Kingdom of Saudi Arabia
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Improvement of green synthesis of metal oxide nanoparticles for biomedical field applications

A graduation project submitted to the Department of Physics in partial fulfillment of the requirements for the degree of Bachelor of Science in Applied Physics

by

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Feb, 2025

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ACKNOWLEDGMENT

قال تعالى : { وَآخِرُ دَعْوَاهُمْ أَنِ الْحَمْدُ لِلَّهِ رَبِّ الْعَالَمِينَ}

الحمدلله ما تناهى درب ولا ختم جهد ولا تم سعيٌ إلا بفضلِه , الحمدلله على البلوغ ثم الحمدلله على التمام الحمدلله حتى يبلغ الحمد منتهاه , لقد أنعم الله علي بإنجاز هذا البحث بعونه وتوفيقه والخروج به على هذه الصورة الحسنة , لقد أصبحت طالبة في تخصص الفيزياء وأنا لا أعلم إن كان هذا مكاني الصحيح ام لا ولكن مع مرور الوقت أيقنت أن الفيزياء أصبحت جزء لا يتجزأ من حياتي وأن كل شي في الحياة معتمد تماماً على الفيزياء ؛ وهذا سبب كافي للسعي وغاية تستحق السير لأجلها , ومن منطلق قول رسولنا الكريم عليه الصلاة والسلام "من لا يشكُر الناس لا يشكٌر الله " أتقدم بأسمى عبارات الشكر والتقدير إلى والدي العزيزين اللذين غرسا في حب العلم منذ الصغر وكان لهما الفضل بعد الله فيما وصلت إليه الآن ثم أتقدم بخالص الشكر والتقدير الى الدكتورة العزيزة (تماضر الهزاني) على ما قدمته لي من علم نافع وعطاء متميز وإرشاد مستمر وعلى انتقاداتها البناءة ونصح وتوجيه من بداية مرحلة البحث حتى نهايته , كما أشكر الاصدقاء ولكل من مد لي يد العون , أو أسدى لي معروفا , أو كانت له إسهامه صغيرة أو كبيرة في إنجاز هذا البحث فله مني خالص الشكر والتقدير.

ABSTRACT

This study presents an innovative and eco-friendly approach for synthesizing $[Fe_3O_4]$ (magnetite) nanoparticles using a mixture of ferric chloride hexahydrate and ferric ammonium sulfate hexahydrate in a 1:2 molar ratio, along with castor and mint leaf essential oils. The synthesis process involves heating the mixture at 80°C for just 10 minutes, making it a fast and efficient method. The prepared $[Fe_3O_4]$ nanoparticles were characterized using Attenuated Total Reflectance (ATR), which provided detailed insights into the chemical bonds and functional groups present in the nanoparticles. The study also proposes a mechanism for the nanoparticle formation, offering valuable theoretical insights alongside the experimental findings. This green chemistry-based method, with its simplicity and rapid synthesis, holds significant potential for both academic research and practical applications in fields such as medicine, electronics, and environmental remediation.

الملخص

يستعرض هذا البحث طريقة مبتكرة وصديقة للبيئة لتحضير جزيئات Fe_3O_4 (المغنيتيت) النانوية باستخدام مزيج من كلوريد الحديد (III) سداسي الماء و كبريتات الأمونيوم الحديدية سداسية الماء بنسبة (٢\١) مولارية، مع إضافة زيوت أوراق النعناع وزيت الخروع. تتضمن عملية التحضير تسخين المزيج عند درجة حرارة ٨٠ درجة مئوية لمدة ١٠ دقائق فقط، مما يجعل هذه الطريقة سريعة وفعّالة. تم تحليل الجزيئات النانوية لـ Fe_3O_4 باستخدام تقنية الانعكاس الكلي المثبط (ATR)، التي قدمت معلومات مفصلة حول الروابط الكيميائية والمجموعات الوظيفية في الجزيئات المحضرة. كما يتضمن البحث عرض آلية مقترحة لتكوين الجزيئات النانوية، مما يضيف قيمة نظرية مهمة للنتائج التجريبية. هذه الطريقة المعتمدة على الكيمياء الخضراء، بفضل بساطتها وسرعتها، تعتبر واعدة في العديد من التطبيقات البحثية والعملية في مجالات مثل الطب، الإلكترونيات، وتنقية البيئة.

Abbreviation & Acronym

Ferric chloride hexahydrate ($FeCl_3 \cdot 6H_2O$, AR)

Sodium hydroxide (NaOH)

Ferric ammonium sulfate hexahydrate ($(NH_4)_2.Fe(SO_4).6H_2O$)

Attenuated Total Reflectance (ATR)

Fourier transform infrared spectroscopy (FT-IR)

CHAPTER 1

Theoretical Background

1.1 Introduction

The field of biomedical research is focused on advancing medical science by developing and enhancing cutting-edge technologies, materials, and methodologies to improve patient care and clinical outcomes. However, this research faces several challenges, such as inefficient drug delivery, limited ability to target affected tissues, and potential harm from therapeutic treatments. The development of nanomaterials presents a promising solution to these issues, as they enable targeted drug delivery to specific cells or tissues, resulting in improved efficacy and reduced side effects. Nanoparticles can be designed and engineered to have optimal dimensions, shapes, and surface properties, allowing for precise delivery, controlled release, and improved biocompatibility. This level of design precision enables more effective treatment of diseases like cancer, cardiovascular disorders, and infections, thus overcoming the major limitations of conventional therapeutic methods [1,2].

Magnetic iron oxide nanoparticles, particularly magnetite (Fe_3O_4), have attracted considerable attention for various applications due to their exceptional properties. Here are some of the key factors driving their appeal:

- **Low toxicity:** Magnetite nanoparticles are generally regarded as biocompatible and non-toxic.

- **Simple preparation:** These nanoparticles can be synthesized using relatively straightforward and cost-effective methods.

- **Ease of separation:** Thanks to their magnetic properties, magnetite nanoparticles can be easily manipulated and separated using an external magnetic field.

- **Light absorption:** Magnetite nanoparticles demonstrate excellent light-absorbing capabilities across the solar spectrum.

- **Recyclability:** Due to their magnetic characteristics, magnetite nanoparticles can be recovered and reused multiple times without significant loss of efficiency or performance [3,4,5,6].

Iron oxides, especially in their nanoscale form, have been shown to have exceptional capabilities and great potential in many fields. Their unique properties make them of great benefit in a wide range of applications, such as catalytic materials, absorbents for wastewater treatment, dyes, magnetic recording devices, coatings, gas sensors, and medicine [7].

Green synthesis methods are becoming increasingly popular for the production of metal nanoparticles due to their many advantages, such as being environmentally friendly, simple, cost-effective, and reproducible. These methods use natural resources such as plants, microorganisms, and biomolecules to reduce metal ions and create nanoparticles. Biological methods are particularly important in green synthesis because they allow the production of nanoparticles under mild conditions, without the need for harsh chemicals or high temperatures [8].

Green synthesis involves using plant extracts and microorganisms (such as fungi or bacteria) as raw materials to produce nanoparticles. This method is non-toxic and natural, making it environmentally friendly. It typically occurs under mild conditions, such as room temperature and atmospheric pressure, resulting in lower risks than chemical methods figure 1.1. Additionally, green synthesis is environmentally safe as it avoids the pollution associated with toxic by-products from chemical synthesis. It is also more cost-effective because it requires less energy [9].

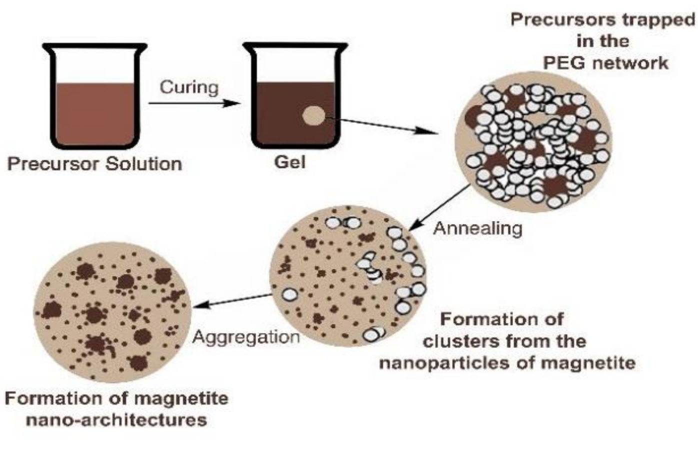


Figure 1.1: Schematic illustration showing the possible formation mechanism of the as-synthesized magnetite nano-architectures [10].

1.2 Literature review

Therefore, Biological synthesis method of nanoparticles, particularly green synthesis has been making considerable headway over the past few years. This method adheres to the principles of green chemistry, which seek the design of chemical processes and substances that minimize the amount of harmful materials used. Eco-friendly approaches exist to synthesize metal oxide nanoparticles using green synthesis. [11]. For example Yossefi et al [12] synthesized the nanoparticles (Fe_3O_4) using a simple co-precipitation method, using Garcinia mangostana fruit peel extract a natural stabilizer. The nanoparticles were primarily for magnetic hyperthermia and cytotoxic properties. The magnetic nanofluids exhibited excellent heating under magnetic field. Data in the cytotoxicity assays showed that the material was more toxic to HCT116 colon cancer cells than to CCD112 normal colon cells. The 10wt. Fe_3O_4 nanoparticles exhibited better selectivity for cancer cells, as indicated by their lower IC50 value(99.80 ug/mL) in HCT116 colon cancer cells compared to 140.80 g/mL in CCS112 colon cells.

CHAPTER 2

Experimental and Techniques

2.1 Attenuated Total Reflectance ART spectrometer

Attenuated Total Reflectance (ATR) is an infrared (IR) sampling technique that uses a crystal with a high refractive index and excellent IR transmission properties. It is commonly used to analyze IR spectra of surfaces or thick and highly absorbing materials that cannot be measured using traditional transmission methods.

The technique works by directing IR radiation at an angle greater than the critical angle, causing total internal reflection. At the reflection point, an evanescent wave penetrates the sample slightly, providing spectral information. Reflection is attenuated at frequencies absorbed by the sample, while full reflection occurs at non-absorbing frequencies. Different ATR crystals are used depending on the sample type, with single-reflection crystals for micro-ATR and multi-reflection crystals for bulk samples.

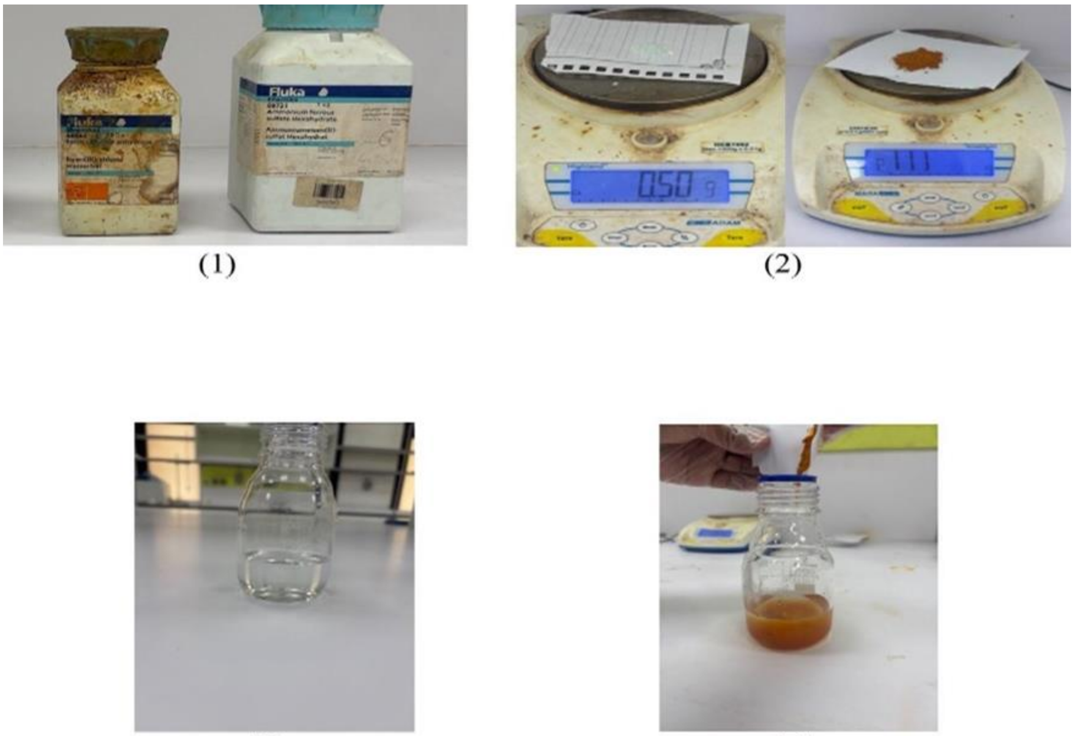
ATR as in figure 2.1 is quick, non-destructive, and requires no sample preparation, making it a popular choice for Fourier Transform Infrared spectroscopies FT-IR [13].

Figure 2. 1: ART spectrometer.

2.2 Powder preparation method

This study describes a method for synthesizing magnetite nanoparticles using a green chemistry approach involving the use of Castro-mint oil extract as a reducing and stabilizing agent. The stepwise synthesis process is mentioned below:

Preparation of Iron salt solution: A solution containing iron chloride salt ($FeCl_{3.}6H_2O$) in molar ratio 1:2 was prepared by dissolving 0.50 g of $((NH_4)_2Fe(SO_4)_2 \cdot 6H_2O)$and 1.11 g of ($FeCl_{3.}6H_2O$)in 100 mL of deionized water contained in a 250 mL beaker.These steps are shown in figure 2.2.



(1) (2) (3) (4)

Figure 2.2: **1)** Images of $(NH_4)_2.Fe(SO_4).6H_2O$ and $FeCl_3 \cdot 6H_2O$ precursors, **2)** Images of analytic balance showing weights of $(NH_4)_2.Fe(SO_4).6H_2O$ and $FeCl_3 \cdot 6H_2O$ precursors, **3)** Images showing 100 mL water measured through a beaker, **4)** Images showing the colour of solvents after adding 0.50 g of $(NH_4)_2.Fe(SO_4).6H_2O$ and 1.11 g of $FeCl_3 \cdot 6H_2O$ precursors to 100 ml H_2O contained in a 250 mL beaker.

Heating and stirring: The iron salt solution was heated to 80°C under mild stirring using a magnetic stirrer and under atmospheric pressure as shown in figure 2.3.

Figure 2.3: Image showing the heating of iron salt solution.

Addition of Castro-mint oil:

After 30 minutes of heating, 5 mL of an aqueous solution of Castro-mint oil was added to the iron salt solution. The addition of Castro-mint oil caused the color of mixture to change from yellowish to reddish-brown, indicating the reduction of iron ions and magnetite nano particles as shown in figure 2.4.

Figure 2.4: Images showing the addition of castro-mint oil to the iron salt.

Precipitation of magnetite: After 10 minutes of adding Castro-mint oil extract to the iron salt solution,20 mL of sodium hydroxide (NaOH) aqueous solution was added to the mixture at a rate of 3 mL/min to precipitate the magnetite nanoparticles uniformly. The reddish-brown mixture turned into a darker color, and suspended nanoparticles were obtained as shown in figure 2.5.

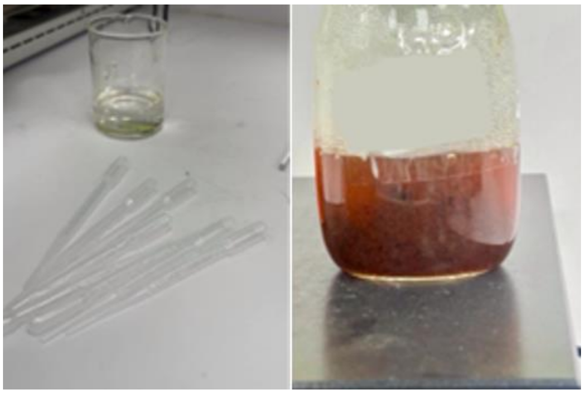


Figure 2.5: Images showing adding the 20 mL of NaOH aqueous solution to the mixture.

Cooling and purification: The mixture was allowed to cool to room temperature.

Magnetite nanoparticles were obtained by decantation, dilution with distilled water, and centrifuged to remove heavy biomaterials from the Castro-mint oil extract as shown in figure 2.6**.**

Figure 2.6: Images showing cooling.

Further purification: The magnetite nanoparticles were purified by dispersing them in sterile distilled water and centrifuged three times at 3000 revolutions per minute to remove any remaining impurities as shown in figure 2.7

Figure 2.7: Images of the centrifuge machine and the centrifuged nanoparticles.

Division of magnetite nanoparticles: The magnetite nanoparticles were divided by centrifuged and let them dry in the oven for 9 hours at 80°C for ART analysis as shown in figure 2.8

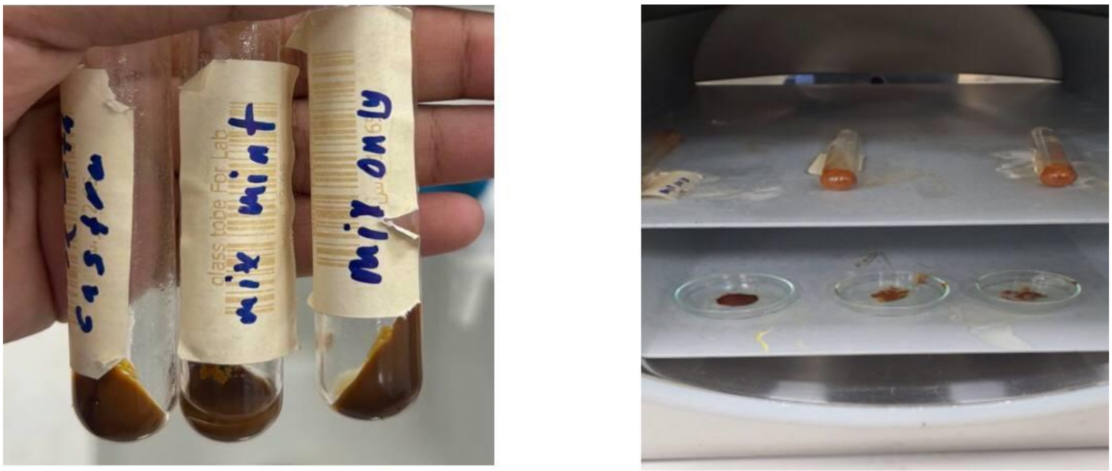


Figure 2.8: Images of dry the magnetite nanoparticles.

CHAPTER 3

Results and Discussion

3.1 Attenuated Total Reflectance Analysis

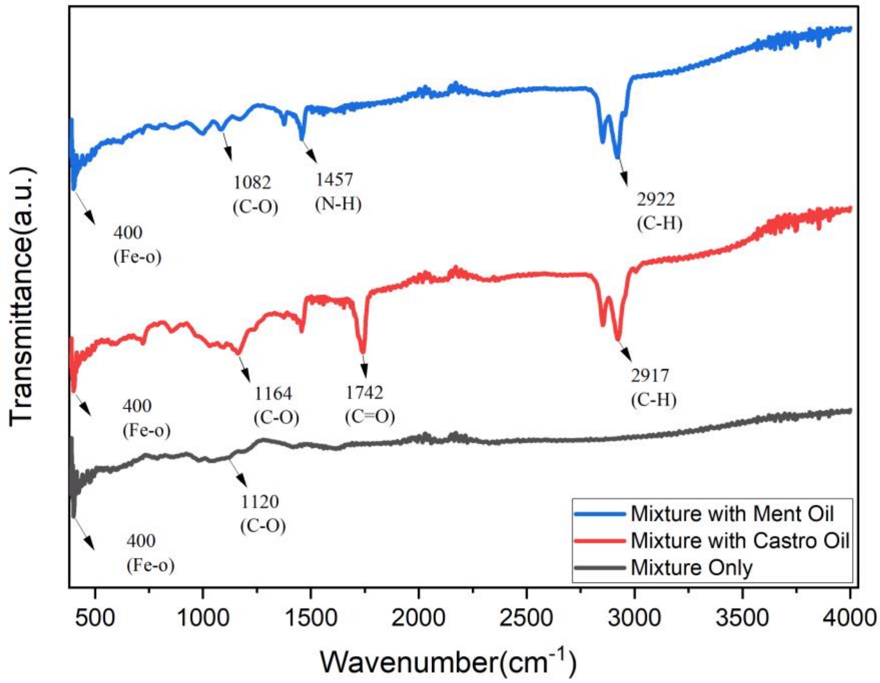


Figure 3.1: FT-IR spectra of the synthesized powdered samples.

ATR and FT-IR spectroscopy are used to identify functional groups and chemical bonds in compounds by measuring their absorption at specific frequencies. A detailed analysis of the absorption frequencies of some of the bonds in Figure (3.1) is given below:

C-O bond (carbon-oxygen):

-The stretching vibrations of the C-O bond appear in the frequency range between 1000 and 1300 cm^{-1}. This absorption is observed in compounds containing functional groups such as alcohols, ethers, and carboxylic acids.

C-H bond (carbon-hydrogen):

-The stretching vibrations of the C-H bond appear in the frequency range between 2800 and 3000 cm^{-1}. This absorption is observed in most organic compounds, where these bonds are abundant. The frequencies can vary slightly depending on the type of hydrocarbon; For example, the stretch vibrations in alkanes appear in the range of 2850-2960 cm^{-1}, while in alkenes they appear at about 3020-3100 cm^{-1}.

C=O (carbon-oxygen double bond):

- The stretch vibrations of the C=O bond appear in the frequency range between 1630 and 1815 cm^{-1}. This absorption is observed in compounds containing carbonyl groups, such as ketones, aldehydes, carboxylic acids, and esters. This absorption is strong and distinct, making it a good indicator of the presence of a carbonyl group in the compound.

Fe-O (iron-oxygen) bond:

-The tension vibrations of the Fe-O bond appear in the frequency range between 500 and 600 cm^{-1}, and in this experiment it appears around 400 cm^{-1}.

This absorption is observed in compounds containing bonds between iron and oxygen, such as iron oxides. The exact frequency can vary depending on the oxidation state of the iron and the type of compound.

Fe-H (iron-hydrogen) bond:

-The tension vibrations of the Fe-H bond appear in the frequency range between 1800 and 2000 cm^{-1}. These bonds are relatively rare and are found in some organometallic compounds where hydrogen is directly bonded to iron.

3.2 Conclusion

This study presents an innovative, sustainable, and eco-friendly approach to synthesizing magnetite (Fe_3O_4) nanoparticles using simple and natural resources. The method involves combining ammonium iron (II) sulfate hexahydrate and ferric chloride hexahydrate in a 1:2 molar ratio, along with essential oils extracted from castor and mint leaves as facilitating agents in the reaction. The mixture is heated at 80°C for only 10 minutes, making the process efficient, fast, and environmentally friendly due to its reliance on green chemistry principles. The synthesized nanoparticles were analyzed using Attenuated Total Reflectance (ATR) spectroscopy, which confirmed the formation of high-quality, ultra-small magnetite nanoparticles. The study also provides a comprehensive theoretical framework to support the experimental findings, adding further credibility to the proposed technique. This approach demonstrates significant potential across various fields. The Fe_3O_4 nanoparticles can be utilized in critical applications such as medicine for drug delivery, electronics for the development of advanced devices, and environmental remediation for improving water and soil quality. By integrating green chemistry with innovative methodologies, this research highlights the potential for creating effective and sustainable solutions with a positive impact on both the environment and society.

References

[1] Aflori, Magdalena. "Smart nanomaterials for biomedical applications—a review." *Nanomaterials* 11.2 (2021): 396.

[2] Materón, Elsa M., et al. "Magnetic nanoparticles in biomedical applications: A review." Applied Surface Science Advances 6 (2021): 100163.

[3] Gupta, Ajay Kumar, and Mona Gupta. "Synthesis and surface engineering of iron oxide nanoparticles for biomedical applications." biomaterials 26.18 (2005): 3995-4021.

[4] Florea, M., et al. "Total oxidation of toluene on ferrite-type catalysts." Catalysis Today 141.3-4 (2009): 361-366.

[5] Xu, Piao, et al. "Use of iron oxide nanomaterials in wastewater treatment: a review." Science of the total environment 424 (2012): 1-10.

[6] Guo, Shaojun, et al. "Monodisperse mesoporous superparamagnetic single-crystal magnetite nanoparticles for drug delivery." Biomaterials 30.10 (2009): 1881-1889.

[7] Mohapatra, M., and S. Anand. "Synthesis and applications of nano-structured iron oxides/hydroxides–a review." International Journal of Engineering, Science and Technology 2.8 (2010).

[8] Nadaroglu, Hayrunnisa, Azize Alaylı Güngör, and Selvi Ince. "Synthesis of nanoparticles by green synthesis method." International Journal of Innovative Research and Reviews 1.1 (2017): 6-9.

[9] Zada, Bakht, Moonhyuk Kwon, and Seon-Won Kim. "Current trends in acetins production: green versus non-green synthesis." Molecules 27.7 (2022): 2255.

[10] Dissanayake, D. M. S. N., M. M. M. G. P. G. Mantilaka, and H. M. T. G. A. Pitawala. "Synthesis of low-cost magnetite nano-architectures from Sri Lankan laterites." Journal of Geological Society of Sri Lanka 21.2 (2020): 90-100.

[11] Ishak, NAI Md, S. K. Kamarudin, and S. N. Timmiati. "Green synthesis of metal and metal oxide nanoparticles via plant extracts: an overview." Materials Research Express 6.11 (2019): 112004.

[12] Mostafa Yusefi, Kamyar Shameli, Ong Su Yee, Sin-Yeang Teow, Ziba Hedayatnasab, Hossein Jahangirian. Green synthesis of Fe_3O_4 nanoparticles stabilized by a garcinia mangostana fruit peel extract for hyperthermia and anticancer activities. International Journal of Nanomedicine 16 (2021) 2515-2532.

[13] Larkin, P. (2011). Chapter 3-Instrumentation and Sampling Methods Infrared and Raman Spectroscopy (pp. 27-54).