Synthesis of CoFe₂O₄ nanoparticles using a various solution combustion techniques and study for its applications

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Abstract

The most conventional approaches for producing spinel ferrite structured nanomaterials. This research illustrates process innovation and excellent execution of cobalt ferrite production technology. Cobalt ferrite offers an extensive range of scientific applications, including magnetic sensors, catalysis, wastewater treatment, and hydrogen generation, among others. CoFe2O4, also known as spinel ferrite nanostructure, has distinct properties and has been inspect with a heterogeneity of fuels. With major consequences for carbon compound structure, doping action, and toxicity reduction. During the procedure, a substantial number of gases such as NOx, etc. are emitted. Several techniques are used to synthesis cobalt ferrite, including the hammer's method, the sol-gel approach, the co-precipitation, the hydrothermal method, the microwave aided method, and the solution combustion method. Other than the loss of abundant excess energy, the combustion approach is the simplest solution. In the future, systematic management will be required to limit toxicity and greenhouse gas emissions to preserve the ecosystem.

Keywords: Spinel ferrites; Nanomaterials; Catalysis; Conventional methods; Technologies; Applications.

1 Introduction

Nowadays, nano-scaled magnetic particles are attracting more interest in the scientific community because of their functional applications in color imaging, catalysis, high-density data storage[1], magnetically guided drug delivery, ferrofluids and magnetic-refrigeration systems. Cobalt ferrites have qualities including moderate saturation magnetization, strong magnetic crystal anisotropy, high coercivity, a wide magneto-optical defluxion angle, and great chemical stability[1]. Because of its features, it has the potential to be used in high-density magnetic recording, permanent magnets, magnetic fluids, catalysis, photo-magnetic materials, and the creation of novel cell thawing agents [8] are all examples of applications. As a result, there is a surge in research interest in magneto-optical memory all around the world. The nano-crystals produced usually have a strong tendency to aggregate, which makes it very difficult to exploit the physicochemical properties. An important approach is the dispersion of nanoparticles in inorganic, polymer, vitreous, and amorphous matrix. Particle agglomeration must be avoided, and particle size must be controlled. Furthermore, such nanocomposites may offer several technical advantages; allow for improved catalytic, magnetic, magneto-optic and mechanical properties of the material. The non-magnetic porosity nature of a Cobalt ferrite NPs favors the formation of unique magnetic crystals with nucleation.

The necessity for environmentally benign methods of preparing inorganic materials has increasingly emerged, particularly when these materials are employed for energy and environmental purposes. According to modern circular economy notions, the overall trend is to replace "commercial" raw resources with natural and waste-derived ones. In this sense, the line "Nature does not produce persistent things... and we should not either" provides chemists with a solid foundation for a sustainable future. Another key term that is intimately related to the others just stated is "efficiency," which is essential for a successful synthesis method. For optimum yield, minimum energy, minimum time, and minimal waste, efficiency is high. In another sense, efficiency is great if the scientist is familiar with the process and its utmost potentialities and possibilities. In this sense, knowledge and expertise with a synthesis technique make the process "efficient," because the synthesis is conducted with the optimal processing settings, resulting in the best material qualities conceivable[2, 3].

Ferrites are reasonable alternatives for use as photocatalysts for hydrogen production[4]; transition metal ferrites have several benefits [3], the most important of which are their low cost, effective catalytic activity, corrosion resistance, and[4], most importantly, their wide bandgap into the visible light spectrum.[3]. The redox activity of these materials, particularly their capacity to store oxygen in their crystalline lattice, is used to choose them[3]. When ferrites are burnt in reducing atmospheres, they tend to generate compounds with oxygen defects, which aids in the fixing of oxygen in existing vacancies[2]. As a result, these materials are good candidates for producing hydrogen from water while also delivering the necessary solar energy.

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2 Synthesis methods of CoFe₂O₄

CoFe2O4 spinel was prepared by coprecipitation (CP), solvothermal, Microwave-solution combustion, solution combustion synthesis, Hydrothermal method, Sol-gel method, Green - synthesis method, Hammer's method, etc. Magnetic nanoparticles of spinel ferrite pique our interest due to their unique features, which include catalytic, optical, magnetic, and electrical capabilities. Electromagnetic absorbers, catalysis, microwave devices, sensors, antimicrobial activity, water purification, nanoelectronics, high-density storage media, medication delivery, and magnetic resonance imaging are some of the potential uses. The universal formula for spinel ferrite is AB2O4, where A and B play the roles of divalent and trivalent cations, respectively. In a typical spinel structure, full divalent cations occupy the tetrahedral positions, while trivalent cations occupy the octahedral interstices. Spinel ferrite nanoparticles have a universal formula of $A^{2+}Fe_2^{3+}O_4$, where A^{2+} has been swapped by suitable divalent metal ions such as Co, Cu, Mg, Zn, Mn, and Ni, among others. Due to its exemplary magneto crystalline anisotropy, temperate saturation magnetization, mechanical inflexibility, and high coercively and chemical stability, cobalt ferrite CoFe₂O₄ is one of the most significant magnetic materials that can be widely used in electronic technologies, particularly on magnetic and magneto-optical recording media. Previously, reported the fabrication of zinc and nickel doped cobalt ferrite nanomaterials using the reverse micelle process and investigated the photocatalytic potential for dye removal under visible light irradiation. In the latest study, materials that are produced and studied for photocatalytic dye degradation utilizing visible light. Many characterization approaches are used to evaluate the structural, morphological, and optical features of the produced photocatalyst Table 1.

Table 1. Literature survey for cobalt ferrite nanomaterials with different viewpoints.

Catalysts	Methods	Materials	Temp. (˚C)	Time (hr.)	Characterization	Summery	Ref.
CoFe₂O₄	Co-precipitation	Iron and cobalt nitrate	250-350	1-6	XRD/SEM/ TEM/VSM/ UV-vis	Better photocatalytic activity, water absorption, production of hydrogen.	[1]
CoFe₂O₄	Co-precipitation	Iron and cobalt nitrate	250-350	1-3	XRD/SEM/TEM	chemical stability, low toxicity, elemental abundance, and exemplary magnetic properties	[2]
TiO₂/CoFe₂O₄	Microwave-hydrothermal	Iron and cobalt nitrate	500/30˚C	1-2	XRD/TEM/FTIR/DSC	Novel method	[3]
CoFe₂O₄	Solution combustion	Iron and cobalt nitrate	250	3	Mossbauer and Raman studies, XRD, FTIR, BET.	Crystalline size	[4]
CoFe₂O₄	Solution combustion	Iron and cobalt nitrate	250	3	Mossbauer and Raman studies, XRD, FTIR, BET.	Different fuels	[5]

3 Preparation technologies of cobalt ferrites

3.1 Solution combustion methods

Not all solution-based preparation approaches are equal in terms of efficiency. Each soft chemical strategy has benefits and drawbacks over the others, such as solution combustion synthesis, sol-gel technique, Pechini-like process, co-precipitation process, and hydrothermal process. The bulk of these processes rely on costly starting ingredients and feature moisture-sensitive intermediates. There are occasions when scaling challenges arise, and efficiency may change depending on the composition/properties of the item to be processed. For example, while the sol-gel synthesis from alkoxide precursors is unquestionably an effective synthesis for silica, alumina, or titania-based powders with regulated porosity, it is time-consuming and inefficient for multi-component compositions, where other techniques are recommended. A main drawback of SCS is that some powder is lost due to the evolution of gases in the combustion process or due to the formation of a "soufflé" of powder coming out of the combustion beaker, for example, it occurs often when sucrose is used as a fuel [6]. In conclusion, selecting a sustainable synthesis will be beneficial for:
- saving energy, time and costs
- increasing the efficiency
- adopting ecofriendly precursors
- minimizing the waste production
- getting knowledge about the synthesis-properties relationships

- producing materials with a benefit for energy, environment, society and economy.

3.1.1 Solution combustion synthesis (SCS)

Solution combustion synthesis (SCS) is a good soft chemical synthesis process in terms of simplicity, cost-efficiency, and final powder quality. SCS is based on a quick and self-sustaining redox reaction in the presence of metal cations between a fuel and an oxidant. Typically, oxidants are metal precursors, such as metal nitrates, and the fuel is any organic substance capable of forming complexes with metal ions of interest, such as citric acid, urea, and glycine. SCS comes from sol-gel chemistry and propellant chemistry, although it uses a faster procedure than sol-gel techniques, and is recommended for multicomponent oxides. Solution combustion synthesis is a time/energy efficient process for producing a wide range of inorganic nano powders with high reactivity and customised flaws. SCS produces end products with excellent phase purity and improved powder features such as greater surface area, narrow particle size distribution, optimal agglomeration, and better sintering performance. Another important advantage is that it can be used with a variety of precursors, both soluble and insoluble. Given this, the combustion process has been extensively used to synthesize various oxides in a nanocrystalline form. SCS has been also recently used to obtain films for applications in electronics. The general procedure is described in the recent reviews on the subject [7]. Solution

combustion synthesis consists of three major processes, which are as follows*:*

(1) formation of the combustion mixture
(2) formation of the gel
(3) combustion of the gel. The desired metal precursors are mixed in a water solution with an organic fuel.

When the solution is dehydrated, a gel network forms in the combustion mixture. A heat or electric source initiates the combustion process between the fuel and the oxidant (i.e., the nitrates and, eventually, an extra oxidant), which are tightly coupled in the gel network. To guarantee that no undesirable compounds are generated, the gel should be decomposed in a single step, uniformly, quickly, and across a small temperature range. After a few seconds, a fluffy powder is formed, the characteristics of which are tightly related to the selected synthesis parameters, such as the reducers-to-oxidizers ratio (), the fuel-to-metal cations ratio (F/M), and many other factors. The fuel is often an organic substance that plays an important role in optimizing the material's characteristics. The fuel frequently serves three functions: reducer, complexing agent, and microstructural template. Both the nature of the fuel and its content in the reaction govern the reaction exothermicity and in turn, guide the process toward attaining the desired powder of the product in terms of phase and powder properties. When employed as a fuel, SCS is a version of the Pechini-based preparation procedures, which are commonly categorized as inorganic sol-gel processes [8,9].

In the Pechini-based processes, organic compounds with carboxylate, hydroxyl and amino functional groups are added as chelating agents to form a gel network with metal nitrate precursors. Therefore, in principle, all the conditions required for a combustion process are effectively present in Pechini based syntheses. To explain, there are certain parallels and distinctions between Pechini-based techniques and SCS-based approaches that are worth addressing in this context. Typically, the amount of fuel in relation to the metal cations (which also represent oxidizers for the oxidising effect of their counter ions) is so high that the reducers-to-oxidizers ratio is outside the combustion range and the combustion process does not occur even under high-temperature treatment. Before the thermal treatment, the nitrate anions are sometimes destroyed under vacuum so that no oxidant is left for combustion. A greater or less intense combustion process may occur in some Pechini process versions when no EDTA is applied and nitrates are not destroyed prior to heat treatment or a combustion aid is provided. For similar reasons, several preparation procedures utilising soft templates and nitrate metal precursors, such as the synthesis of metallic silver sponges from dextran as a framework-generating agent and silver nitrate as the metal precursor, may be considered solution combustion-based approaches Figure 1 [10,11].
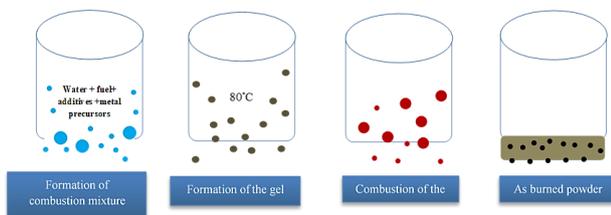

Figure 1. Schematic diagram of the synthesis of solution combustion method for powder formation.

3.1.2 Microwave heating

Another emerging and promising initiation type is the microwave oven. Microwave initiation cathode powders had better microstructural and textural features (surface area, crystal size, grain size) and reduced area interface resistance. Most of the nano powders are prepared by conventional initiation in the oven and microwave initiation is confronted. Reduced agglomeration and more uniform size distribution were obtained by microwave heating. Microwave initiation has as well some limitations, like the high cost of the equipment, the low size limit of the combustion reactor and the impossibility to monitor the particle growth mechanism during the combustion process Figure 2 [12,13].
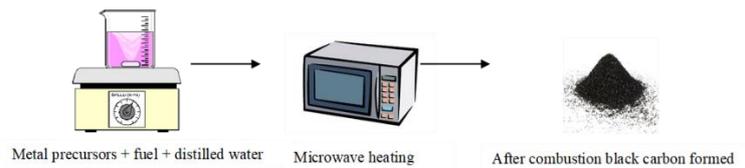

Figure 2. Schematic view diagram for Microwave-assisted combustion synthesis method

3.1.3 Sol-gel method and Synthesis of microemulsion

Nanomaterial produced by solgel synthesis. This is very facial, easy and the salt are same in poured into the solution in presence of citric acid is used. The coordinating agent into the solution to form gel, upon evaporation of water, forms a gel structure. pH is maintained by addition of ammonia solution. At this time, the solution is used to more effective. Advantage of solgel route is low annealing temperature, excellent capability of controlled microstructure Figure 3 [14].

Nanoparticles are formed two immiscible liquids stabilized by a thin film of surfactant. The precipitates are separated washed and dried Figure 4 [15].
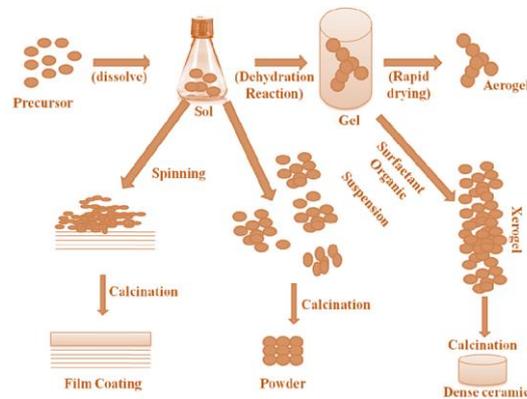

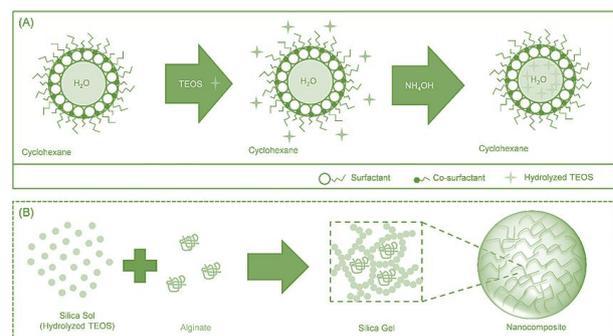**Figure3.** solgel route for Cobalt ferrite nanomaterials

Figure 4. Microemulsion method for CoFe2O4 NPs

3.1.4 Others methods

Because of the availability of supplies, raw materials, and equipment. Other methods, such as hammer's, hydrothermal, and so on, are used to overcome. In sectors with a wide range of uses, nanomaterials can be manufactured in furnaces. The image of appropriateness is more limited due to the high expense of equipment and facilities. In terms of procedural fact, the function of materials is employed. The hypothermal approach necessitates the use of autoclaves, which aid in the production of powder nanomaterials [16].

$CoFe_2O_4$ previously synthesized by the mechanical milling (BM) technique, the procedure consisted of employing metallic Fe and Co_3O_4 as precursors in a molar ratio of 2:1. Once the material was in stoichiometric amounts, this was mixed and exposed to $700°C$ by 4 hours. Following that, the sample was mechanical milled for 12 hours in order to get the necessary spinel phase while also reducing particle size [3]. To identify the temperatures to be employed during sample calcination, thermogravimetric studies were performed on powders produced during each synthesis. These experiments were conducted in a TGA Instrument TA Q500 with an initial sample weight of 14 to 15 mg placed in a platinum crucible and a heating rate of 10 C/min from ambient temperature to $980°C$ under an air flow.

4 Classification of fuels

The first thing to consider is that these four groups have varying levels of complexing capacity with metal cations. Carboxylic groups, for example, may The bulk of metal cations are complexed, but complexes with alkaline earth cations are less common. Hydroxyl groups are more convenient in the presence of a large concentration of these metal cations. Alternatively, -NR2 containing fuels is a viable option. The strength of the combustion reaction is another factor that is related to the kind of functional group. In general, -NR2 During the combustion reaction, fuels are more redox active than –OH, which is more active than –COOH, increasing the intensity of the combustion process. A brief description of the key fuels in this initial categorization is provided below, along with a description of the corresponding category. It is worth noting that, while each fuel has unique characteristics, some properties are shared by all fuels in the same category [17,18].

4.1 Main functional groups present in the fuel molecules (alone or in combination)

- Fuels with carboxylic functions as the main functional groups
- Fuels with hydroxyl functions as the main functional groups
- Fuels with amino functions as the main functional groups
- Fuels with several functions

Origin of the fuels
- Commercial fuels
- Naturally occurring fuels
- Waste derived fuels

Solubility of the fuel in water
- Soluble fuels
- Insoluble fuels

Number of fuels in the combustion mixture
- Single fuels
- Mixed fuels

Number of units in a fuel molecule
- Normal microstructural templates
- Special microstructural templates

Reducing the power of the fuel molecule and fuel mixtures
- Low reducing power
- High reducing power

4.2 Methodology of fuels in combustion reaction

For example, citric acid ($C_6H_8O_7$) comes into the first group of this categorization. It is a low-cost fuel that may be used in conjunction with nitrates at low ignition temperatures (200–250 °C). It has three carboxylic and one hydroxyl group for coordinating metal ions and maintaining compositional uniformity via gel formation. Citric acid is a high carbon, nitrogen-free fuel. When the citric acid gel is burned, it produces a large amount of gas, which improves the powder's characteristics [19,20].

Ascorbic acid and tartaric acid, which are rich carbon and nitrogen-free fuels often utilized for slow combustion reactions, have a limited complexation capacity precipitation can begin early with several cation oxidants toward metal cations. The combustion processes with these acids are slow and can be enhanced to produce better powder characteristics. Sluggish combustion, as will be addressed later, maybe the best option for safety reasons or to avoid excessive powder dispersion, and scaling up is easier with sluggish combustion. If some of these parameters cannot be controlled (because of a lacking of knowledge or because of other circumstances), reproducibility is not fully ensured in SCS. Therefore, it must be taken into consideration that SCS is a powerful methodology only when all the relevant synthesis parameters are controlled and their effect on the material's properties is well known [21].

Due to the obvious prevalence of the carboxylic acid functional groups, aspartic acid ($C_4H_7NO_4$) and glutamic acid ($C_5H_9NO_4$) are acidic -amino acids with two carboxylic (—COOH) and one amino (—NH2) groups. The identical compounds can also be positioned in an intermediate zone between and, since the presence of one amino group is important in supporting better coordination of metal ions and maintaining compositional homogeneity during gel formation. The inexpensive cost of organic precursors and the low ignition temperatures (200–250 °C) are benefits. Oxalic acid ($C_2H_2O_4$) is a dicarboxylic acid that may also be used to generate electricity. It has been discovered, for example, that oxalic acid may create pure MgO powders with smaller crystal sizes and greater characteristics when compared to other fuels, like citric acid. Because of the presence of hydroxyl moieties in their ring-shaped structure, carbohydrates such as glucose or dextrose ($C_6H_{12}O_6$), sucrose ($C_{12}H_{22}O_{11}$), cellulose (($C_6H_{10}O_5$) $_n$), and sorbitol ($C_6H_{14}O_6$). Ethylene glycol ($C_2H_6O_2$) has a hydroxyl group preponderance. It may form a gel network with metal cations and interact with them via steric entrapment [22].

Ethylenediaminetetraacetic acid (EDTA) ($C_{10}H_{16}N_2O_8$) is a one-of-a-kind fuel with four carboxylic acid groups and two amino groups, although it would be better placed in the intermediate zone. When insoluble metal compounds precipitate with other fuels, EDTA is employed to avoid the problem of precipitation.

The most widely utilized fuel is urea (CH_4N_2O), which has two amino groups connected to a ketone group. Arginine ($C_6H_{14}N_4O_2$) and tryptophan ($C_{10}H_{10}N_2O_2$) are -amino acids because they have one amino group attached to the carboxyl group at the -position. They may form complexes with metal ions, resulting in a homogenous gel, and they can burn at low ignition temperatures. Tryptophan is a slightly basic -amino acid, whereas arginine is a highly basic one. Arginine has two amino groups (—NH2) and one carboxyl group (—COOH), whereas tryptophan has one amino group and a heterocyclic moiety with nitrogen as the heteroatom. Because of the predominance of amino groups, they are both fuels. Dimethyl urea ($C_3H_8N_2O$), a unique fuel that is not an amino acid, is also employed as a combustion fuel in certain combustion processes. It produces furious combustion with extreme exothermicity [23].

Hydrazine monohydrate ($N_2H_4.H_2O$) is a powerful reducing fuel that may generate explosive combinations with air (when concentration is more than 4.7 per cent by volume). It was initially

utilized in the production of pyrotechnics as well as for power generation in propulsion applications such as thrusters for orbiting satellites. It is a useful fuel when carbon impurities are extremely undesired in the product and when oxidation state control is necessary throughout the combustion process [24].

Hexamethylene tetramine ($(CH_2)_6N_4$) is another amino group-containing fuel (HMTA). HMTA is an organic heterocyclic molecule that dissolves easily in water and forms complexes. The combustion of HMTA is very exothermic and explosive due to the high enthalpy of combustion. As a result, HMTA serves as the foundation for the production of research-developed explosives (RDX). Some organic compounds have an equal number of various functional groups and hence fall into the fourth category of this categorization. ($C_2H_5NO_2$), for example, falls and has a carboxylic acid group at one end and an amino group at the other. It is one of the least expensive -amino acids known, and it functions as a complexing/coordinating agent for a variety of metal ions.

The glycine molecule possesses a zwitterionic characteristic that permits it to form complexes with metal ions of varying ionic sizes and charges, avoiding selective precipitation and preserving component compositional homogeneity. Valine ($C_5H_{11}NO_2$) and phenylalanine ($C_9H_{11}NO_2$) are well-known neutral -amino acids that have one amino and one carboxyl group at the -position and hence belong to fuels. The combustion process is similar to the glycine combustion reaction, but with higher gas evolution. Some carbons, such as carbon nanotubes, can also be used as fuels, albeit they are not removed in burnt powders without extra heat treatment. These fuels belong because their interaction with metal cations is most likely utilized via adsorption onto the faulty oxidized carbon species (mainly hydroxyl, carboxyl, and laconic groups) on the surface of the carbon nanotube. Sm^{3+} ion-doped nanoparticles of $CoFe_2O_4$ spinel ferrite. Sm^{3+} is a powerful additive that may alter the distribution shape of cations at tetrahedral and octahedral spinel sites. The 4f5 electron configuration of Sm^{3+} is predicted to significantly alter the spinel lattice's structural and magnetic characteristics. Furthermore, Sm-doped cobalt ferrite is a strong ferromagnet with a high Curie temperature, and Sm-Co alloy is a well-known permanent magnet, both of which exhibit outstanding heat resistance and temperature-dependent properties. The sol–gel auto combustion technique was used to create nanoparticles of $CoFe_{2-x}Sm_xO_4$ (x = 0, 0.02, 0.04, 0.06 at. percent). It is discovered that Sm doping greatly raises the value of the coercive field while causing only a little change in saturation magnetization. It was demonstrated that particle size and magnetic anisotropy have a role in the observed occurrences.

4.3 Precautions and limitations

The combustion process is simple and efficient, although a few precautionary measures are necessary while performing the process, either for safety reasons or for intrinsic limitations of this methodology [25].

4.3.1 Knowledge of parameters

Complete information about the fuel and its behavior should be compiled. Initially, small-batch reactions are useful to understand the behavior of the fuel, the oxidants and the other synthesis parameters, to establish synthesis-structure-properties relationships, which are essential for preparing reproducible and high-performance materials. Special care should be taken in understanding the mechanisms of the combustion process, through a deep characterization of the gas output and of the combustion mass transformations during the synthesis through complementary techniques. This could be very useful as well for safety reasons [26].

4.3.2 Knowledge of parameters

The combustion process is spontaneous and vigorous and safety issues must be carefully considered. A large amount of heat (exothermicity) is released in a very short duration. There must be an arrangement for safe ventilation of the gaseous products to avoid any kind of damage to the experimenter. The combustion process should be carried out in a wide-mouthed apparatus, with large volumes. Narrow opening containers, in general, may cause an explosion during the evolution of a significant amount of gaseous products. They recently devised an airless technique for preparing catalytic NPs in a beaker with a perforated rubber stopper, and they were successful in the synthesis. The vigorous process can be also contained in a microreactor array system for combinatorial synthesis. Another drawback is the possible production of hazardous gases, like NOx and CO, derived from incomplete combustion.

As a result, while selecting the fuel type/quantity, safety and environmental concerns must be carefully examined. Stoichiometric Φ values and fuels that favor rapid and complete combustion are generally recommended. If the combustion process is too violent at stoichiometric Φ values, the use of mixed fuels might be a good choice, when the secondary fuel helps in controlling the intensity of the combustion process. In the case of industrial scale-up combustion processes, NOx abatement reactors are recommended.

Overall, the high degree of control of the process through the selection of the fuel-related parameters allows taking all the required safety measurements even in scale-up and mass combustion reactions. A self-sustained smoldering combustion process - similar to the combustion process occurring - has been applied as a safe and efficient alternative to the incineration of the solid or liquid wastes, by embedding the wastes in a porous matrix, to promote the high surface area for heat and mass transfer [27].

4.3.3 Reactivity and sensitivity of the powder

Combustion-synthesized powders are very reactive due to their high surface area. The right conditions of calculations and their proper storage in desiccators are recommended to avoid any attack from atmospheric gases (e.g., formation of carbonates due to attack of atmospheric carbon dioxide) and moisture. Yield.
Up to about 20 wt. % of the calculated amount is often lost during combustion due to a large amount of gas evolving in a few seconds, although the amount of lost powder depends on the intensity of the process and in turn on the chemical composition of the final powder, the fuel type/amount, the proportion of the combustion mass to the combustion beaker, the beaker type, the ignition mode/type.

This inconvenience can be partially overcome by using special combustion reactors or fixing a protective grid over the combustion beaker, although, these solutions are not applicable in the case of violent gas evolution. Alternatively, a semi-closed system, with the double advantage of the powder losing prevention and possibility to collect and examine the evolved gases [28].

4.3.4 Importance of controlling parameters and presence of carbon residues

The high versatility in methods is mainly due to the high number of parameters that can be changed to produce a material with the required properties.

Unless fuels that do not contain carbon atoms, such as hydrazine, are employed, a fluctuating proportion of residual carbon is commonly found in the as-burned powders. The quantity of leftover carbon is primarily determined by the kind and amount of fuel used, but it may also be affected by other factors like as the geometry/type of beaker, the amount of powder generated, and the presence of external templates. The existence of residual carbon is not a concern while making metal-carbon and metal oxide/carbon

nanocomposites. According to the literature, the kind and amount of such residual carbonates are affected by the type of fuel and the calcination temperature. If residual carbon represents a problem, the calcined powder can be partially or cleaned by an ultrasonic treatment followed by drying [29].

5 Applications

Unsubstituted Ferrites are commonly employed in digital recording, computer memory cores, satellite communication, microwave radars, audio-video equipment, TV tube flyback transformers, and mechanical filters, antenna cores in radio receivers, biological activity, and many other applications due to their ease of production, superior magnetization, high resistivity, and other valuable properties. The most essential qualities of cobalt ferrites are saturation magnetization, coercive force, absorption band, and remanent magnetization. These properties may be achieved by varying the compositions, method of synthesis, and sintering temperature, among other things, depending on the application.

Other cobalt ferrites applications include recording heads, shield beads and chokes, transducers, catalysis, optical properties, high-density write-once optical recording, magnetic sensors, pollution control, ferrite electrodes, power transformers and chokes, pulse and wideband transformers, magnetic deflection structure, drug delivery, pesticide, magnetic recording, pigments, inks, and paints Figure5 [30].
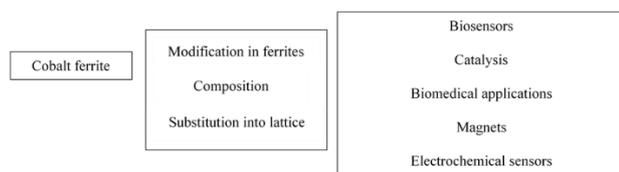

Figure5. Cobalt ferrite applications

6 Conclusion

According to our study, there has been a lot of interest in spinel ferrites during the previous few decades. Doping has also been examined with varied effects, however our research exhibits magnetic and electric characteristics of $CoFe_2O_4$ as a function of theoretical route, composition, and sintering temperature, with an emphasis on biomedical applications magnetic particles. People interested in magnetic material research and development may find the collection useful.

Ethical issue

Author is aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Author adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The author declares that there is no conflict of interest that would prejudice the impartiality of this scientific work.

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