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SYNTHESIZED Co_3O_4 NANOPARTICLES BY SOLUTION COMBUSTION METHOD AND THEIR ENVIRONMENTAL REMEDIATION APPLICATIONS

The unique features and prospective applications of Co_3O_4 nanoparticles to address environmental concerns have attracted significant interest. As a way to produce Co_3O_4 nanoparticles efficiently, the solution combustion technique is the main emphasis of this study, which also explores the synthesis, characterization, and many applications of these particles. Co_3O_4 nanoparticles are an attractive choice for energy storage, sensitive sensors, environmental remediation, and catalysis due to their remarkable features, which include their immense surface area, porosity, density, and magnetic properties. Moreover, Co_3O4 nanoparticles show potential characteristics in porosity, electrical performance and environmental remediation such as sensitive sensors and water treatment using XRD, SEM, TEM, XPS and BET instruments. Using Co_3O_4 nanoparticles in smart technology devices offers a different way to accomplish sustainable development objectives like reducing air pollution, slowing down global warming, and water treatment. The comprehensive overview provided by this review highlights the necessity of further research and investigation to fully realize Co_3O_4 nanoparticles' potential in addressing serious environmental challenges.

Keywords: Co_3O_4 nanoparticles, solution combustion, porosity, sensitive sensors, environmental remediation.

Introduction

It is known Particles which have size from 1 nm to 100 nm called nanoparticles. Nanoparticles are one of the important topics of the 21th century that have drawn attention of researchers and collogues. Large surface area, very small size and wide amount pores make nanoparticles unique compare to their bulk size. There is need

to achieve the UN 17 goals, for new and smart technology devices. Due to the pore and large surface area of Co_3O_4 nanoparticles, these nanoparticles show unique properties that can be used in smart technology devices as alternative materials for achieving the (UN 17) goals instead of traditional devices spatially, to control the air pollution, Global warming and water treatment. Co_3O_4 nanoparticles are good candidates for a variety of applications, including energy storage, remediation of the environment, sensitive sensors and catalysis, due to their density, melting temperature, magnetic features, and band gap [10, 11]. The synthesis of Co_3O_4 nanoparticles by solution combustion, their importance, and the possible impact they have in a wide range of sectors are highlighted in this review, underscoring the need for more investigation and study of their numerous potential uses, represents a comprehensive overview of the synthesis, characterization, and applications of Co_3O_4 nanoparticles, focusing on the solution combustion method as a versatile and efficient approach for their production [15, 9]. There are limited publications that describe Co_3O_4 nanoparticles synthesized by solution combustion method are promise materials for environmental remediation and sensitive sensors [6]. Further researches is need to provide a comprehensive knowledgement of Co_3O_4 nanoparticles behavior.

Materials and methods

I performed a bibliographic study on the characteristics and solution combustion synthesis of Co_3O_4 nanoparticles. To fill the knowledge gap on the topic, relevant books and articles were consulted in the present research. This article includes (books, magazines, websites, etc.) as sources.

2. Cobalt (II)(III) nanoparticles

Cobalt oxide has a (6.11 gr/cm^3) density and melts at (895^{o}C), these particles are magnetic materials with a white tone. likewise, they have positive charge carriers considering they are P-type semiconductors [1, 12], the chemical name for the Co_3O_4 compound is cobalt (II, III) oxide, due to its mixed valence of Co(II) and Co(III), some cobalt atoms have a charge of (Co^{+2}), while others have a charge of (Co^{+3}). This can be shown by writing the formula as ($CoO•Co_3O_4$). Energy required to excite electrons from the valence band to the conduction band is known as the band gap and they have two of them. A major aspect of these applications is the synthesis of Co_3O_4 nanoparticles, and the solution combustion approach has proven to be a flexible and effective way to create these nanomaterials with specific properties [1,7]. As shown in (Fig 1), recently many collogues and researchers had focused on, many researches and articles in a wide range of fields published, due to the unique properties and many proses of Co_3O_4 nanoparticles.

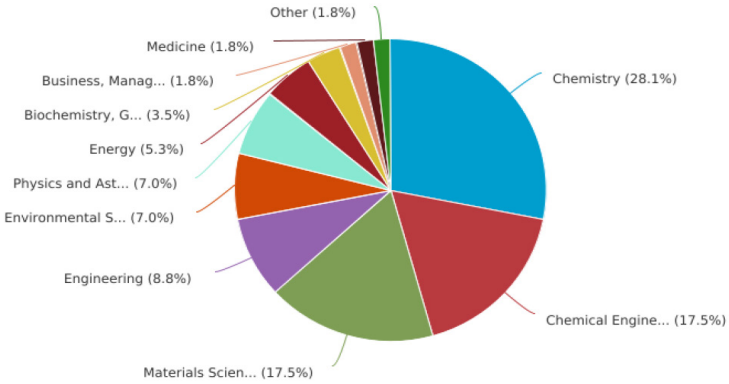

Figure 1 – Recently publications of Co_3O_4 nanoparticles in a wide range of fields.

Recently some publications have examined the synthesis of Co_3O_4 nanoparticles using solution combustion, examining crucial factors such as the ratio of fuel to oxide, precursor materials, and reaction conditions. For instance, Acedera et al. (2020) investigated the use of porous Co_3O_4 nanoparticles in an alkaline medium as electrocatalysts for the oxygen evolution reaction (OER), highlighting their potential in renewable energy technologies and emphasizing the vital role of these materials in energy conversion technologies [2]. Kumar et al. (2021) investigated how the structural and physical properties of nanocrystalline Co_3O_4 were affected by the fuel-to-oxidizer ratio [3]. It is essential to understand the structure of Co_3O_4 nanoparticles to emphasize the adaptability of these nanoparticles in energy storage devices, in order to maximize their effectiveness by concentrating on morphological characteristics. Keneshbekova et al. (2023) explored the Morphological features of Co_3O_4 nanoparticles obtained by the solution combustion method, providing valuable insights into their structural characteristics and the finer points of particle creation. Beyond energy storage and electrocatalysis, Co_3O_4 nanoparticles have found applications in environmental remediation [7].

Results and discussion

3.1 Synthesis of Co_3O_4 Nanoparticles by Solution Combustion Method

The solution combustion method is a widely employed technique for synthesizing Co_3O_4 nanoparticles due to its simplicity and scalability. The procedure of solution combustion method includes a controlled exothermic reaction

between cobalt containing precursors and suitable fuel solution, for the formation of Co_3O_4 nanoparticles [1,7, 14].

3.1 Experimental Procedure

Materials: Cobalt nitrate hexahydrate ($Co(NO_3)2 \cdot 6H_2O$), Citric acid (Fuel), Deionized water, Ethanol and Crucible.

Synthesis Steps

Step 1: Precursor Solution Preparation

Weigh a calculated amount of cobalt nitrate hexahydrate ($Co(NO_3)_2 \cdot 6H_2O$) based on the desired Co_3O_4 nanoparticle size. Dissolve the cobalt nitrate hexahydrate in deionized water to form a clear solution [3].

Step 2: Fuel Addition

Add a stoichiometric amount of citric acid as the fuel to the cobalt nitrate solution. Stir the solution vigorously to ensure complete dissolution of the fuel.

Step 3: Solution Combustion

Place the crucible containing the precursor solution on a hotplate. Heat the solution to initiate the combustion reaction. The exothermic reaction results in the formation of Co_3O_4 nanoparticles.

Step 4: Quenching and Washing

Once the combustion reaction is complete, quench the reaction by adding ethanol to the hot solution. Collect the precipitated Co_3O_4 nanoparticles by centrifugation or filtration. Wash the obtained nanoparticles with ethanol and deionized water to remove residual reactants.

Step 5: Drying and Annealing

Dry the collected nanoparticles at a moderate temperature. Optionally, anneal the dried nanoparticles to enhance crystallinity and structural stability [3].

3.2 Mechanism of Solution Combustion Synthesis:

The combustion reaction is a decomposition reaction of precursors, fuel oxidation, combustion reaction and cobalt oxide formation steps, firstly Cobalt nitrate hexahydrate decomposes upon heating to produce cobalt oxide species (2). The citric acid fuel acts as a reducing agent and will oxidized (3). The generated carbo monoxide (CO) from the fuel reacts with the oxygen released during the decomposition of cobalt nitrate, resulting in the combustion of the fuel (4). The high-temperature environment facilitates the formation of Co3O4 nanoparticles (5).

$$2Co(NO_3)_2 \cdot 6H_2O \xrightarrow{\text{Heat}} 2CoO + 4NO_2 + 12H_2O + O_2$$

$$2C_6H_8O_7 + 6O_2 \xrightarrow{\text{Combustion}} 6CO_2 + 8H_2O + 6CO$$

$$6CO + 6NO_2 \xrightarrow{\text{Heat}} 6CO_2 + 3N_2 + 3O_2$$

$$6CoO + 4O_2 \xrightarrow{\text{High Temperature}} 2Co_3O_4$$

4. Characterization

Powder X-ray diffraction (XRD) and Raman spectroscopy (RS) are used to characterize the structural properties of the Co3O4 nanoparticles. First, the Co3O4 nanoparticles have been found to be a crystalline nature by XRD pattern. For the observation of their surface morphology and particle size The scanning electron microscopy (SEM) and the transmission electron microscopy (TEM) were used as shown in (Fig 2) [3]. It may be concluded that the cobalt oxide consists of particles measuring (12-60 nm), with the average size about (36 nm) and loose arrangement featuring several empty spaces from the SEM and TEM imaging results [1, 12].

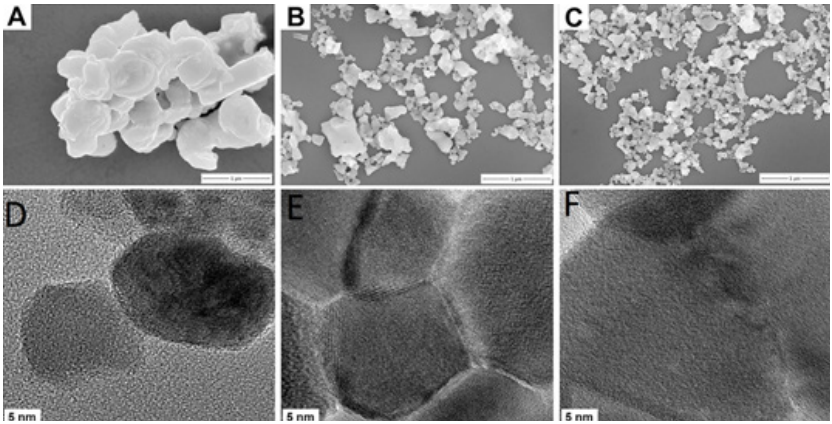

Figure 2 – SEM image of samples A, B and C;
TEM image of samples A, E, and F [3]

XPS is performed to determine the composition and oxidation states of Co_3O_4 nanoparticles [5, 8]. Ashok el al. (2018) investigated The surface elemental composition for further evaluated using XPS analysis to confirm the findings from TEM and SEM images. The peak area was a function of the number of Ag atoms on the surface. Highly dispersed Ag atoms on the surface cause an increase in the intensity of (Ag 3d) spectrum lines. From this aspect, the amount of (Ag 3d) in the surface is decreasing in the order of (AgCo-21) > (AgCo-11) > (AgCo-12). This could be due to the synthesized silver in the first stage of combustion being covered with the cobalt synthesized later. This sequence of combustion reduces, the surface Ag content in (AgCo-12) compared to the other two cases [8, 9].

BET is performed to evaluate the specific surface area and porosity of Co_3O_4 nanoparticles [2]. According to the (Table 1), synthesis methods, raw materials

and temperature are effectiveness on the porosity and specific surface area of the obtained nanocatalyst.

Table 1 – A comparison of Specific surface area and corresponding preparation temperature of several Co_3O_4 nanostructures

No	Used synthesis	Precursors	Catalyst agent	BET result	Heat	References
1	Hydro thermal method	$(Co(NO_3)_26H_2O$ and urea $(CO(NH_2)2)$ in deionized water	Co_3O_4 nanoplate	45.5 m2g-1	325 C°	[18]
2	Solution combustion	$(Co(NO_3)_26H_2O$; Aldrich,99%) and urea $((NH2)_2CO)$	Co_3O_4 nanoparticles	39 m2g-1	800 C°	[16]
3	Solution combustion	$(C_4H_6O_4Co \cdot 4H2O)$ and D-(+)$(C_6H_{12}O_6$; ≥99.5% (GC),	spinel-structured Co_3O_4 powder	3 m2g-1	700 C°	[1]
4	Sol-gel method	$(Co(NO_3)_26H_2O)$ and PEG in deionized water	Co_3O_4 nanotube	56-48 m2g-1	350 C°	[17]
5	Sol-gel method	$(Co(NO_3)_26H_2O)$ and PEG in deionized water	Co_3O_4 bulk	20.9 m2g-1	700 C°	[17]
6	Solution combustion	$(Co(NO_3)_26H_2O)$ and urea $(CO(NH_2)_2)$ in deionized water	Nano-crystalline Co_3O_4	10 m2g-1	600 C°	[5]
7	Solution combustion	$(AgNO_3)$, $(Co(NO_3)_26H_2O)$, $(C_2H_5NO_2)$ with water.	silver-cobalt nanopowders		250 C°	[8]
8	Reactive calcination route	$(Co(NO_3)_2 \cdot 6H_2O)$ and$(Mn(NO_3)_2 \cdot 4H_2O)$ in deionized water	Mn promoted Co_3O_4 spinel (Cat-S)	57.43 m2g-1	420 C°	[19]

5. Application

Cobalt oxide nanoparticles have a wide range of applications such as a few examples of these nanoparticles are: Applications in biomedical science (antibacterial, antifungal, antiviral, antileishmanial, medications, anticancer, and

drug delivery), gas sensors, solar specific absorbing materials, anode materials in lithium-ion batteries, energy storage, pigments and dyes, electromagnetic field-emitting materials, capacitors, diverse catalysis, magneto-resistive devices, and electronic lightweight films. Zhao et al. (2021) used laser-induced graphene to incorporate Co_3O_4 nanoparticles for a flexible and highly sensitive enzyme-free glucose biosensor, highlighting their versatility in sensing applications [13]. Co_3O_4 nanoparticles have found applications in environmental remediation. Anele et al. (2022) discussed recent trends in the environmental remediation of bacteria in wastewater using Co_3O_4 nanoparticles. The properties of Co_3O_4 nanoparticles have been taken advantage of in environmental remediation applications, such as the degradation of dyes, dye waste, and antibiotics, similar to some applications of other nanoparticles. These include the photocatalytic degradation of hazardous dye waste in wastewater using Co_3O_4 nanostructures synthesized with A. linearis leaf extract. the photocatalytic degradation of hazardous dye waste and the catalytic reduction of (4- nitroaniline) and (4-nitrophenol) using Co_3O_4 nanoparticles synthesized with Azadirachta indica leaf extract and methyl orange dye adsorption using Co_3O_4 nanoparticles [20].

Conclusion

Cobalt oxide nanoparticles are synthesized via solution combustion synthesis using cobalt(II) acetate tetrahydrate as precursor and glucose as fuel. Obtained nanoparticles have an average size of 36 nm and demonstrate good magnetic and porosity properties as a suitable material for pollution absorbent in water treatment. The solution combustion synthesis method offers advantages in terms of cost and safety, making it a potential route for the large-scale synthesis of Co_3O_4 nanoparticles. Further adjustments and optimizations can be made based on specific research goals and requirements. Various characterization techniques have been employed in these studies, including X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), (XPS) and (TET) measurements. These techniques collectively provide a comprehensive understanding of the structural, morphological, porosity and electrochemical properties of Co_3O_4 nanoparticles. The solution combustion method has proven to be a versatile and effective approach for synthesizing Co_3O_4 nanoparticles with tailored characteristics. These nanoparticles find applications in diverse fields, including energy storage, environmental remediation, and biomedical applications. The thorough exploration of synthesis parameters, morphological features, and applications in the reviewed literature emphasizes the significance of Co_3O_4 nanoparticles as promising materials for various technological advancements. The wide range of applications, underscores the significance of Co_3O_4 nanoparticles in diverse scientific and technological domains.

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ЕРІТІНДІЛЕРДІ ЖАҒУ ӘДІСІМЕН Co_3O_4 СИНТЕЗДЕЛГЕН НАНОБӨЛШЕКТЕР ЖӘНЕ ОЛАРДЫ ҚОШАҒАН ОРТАҒА ҚОЛДАНУ

Экологиялық проблемаларды шешу үшін Co_3O_4 нанобөлшектерінің бірегей қасиеттері мен перспективалық қолданбалары үлкен қызығушылық тудырды. Co_3O_4 нанобөлшектерін тиімді өндіру тәсілі ретінде еріткіштің жану әдісі осы бөлшектердің синтезін, сипаттамасын және көптеген қолдануларын зерттейтін осы зерттеудің негізгі бағыты болып табылады. Co_3O_4 нанобөлшектері үлкен бетінің ауданы, кеуектілігі, тығыздығы және магниттік қасиеттерін қамтитын керемет ерекшеліктеріне байланысты энергияны сақтау, сезу, қоршаған ортаны қалпына келтіру және катализ үшін тартымды таңдау болып табылады. Co_3O_4 нанобөлшектері потенциалды кеуектілікті, электрлік өнімділікті және XRD, SEM, TEM, XPS және BET аспаптарын пайдаланып сезу және суды тазарту сияқты қоршаған ортаны қалпына келтіру қасиеттерін көрсетеді. Смарт-технологиялық құрылғыларда Co_3O_4 нанобөлшектерін пайдалану ауаның ластануын азайту, жаһандық жылынуды бәсеңдету және суды тазарту сияқты тұрақтылық мақсаттарына қол жеткізудің тағы бір жолын ұсынады. Осы шолуда берілген жан-жақты шолу күрделі экологиялық мәселелерді

шешуде Co_3O_4 нанобөлшектерінің әлеуетін толық іске асыру үшін одан әрі зерттеулер мен әзірлемелердің қажеттілігін көрсетеді.

Кілтті сөздер: Co_3O_4 нанобөлшектері, ерітіндінің жануы, кеуектілік, сезімтал сенсорлар, қоршаған ортаны қалпына келтіру.

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СИНТЕЗИРОВАННЫЕ НАНОЧАСТИЦЫ CO_3O_4 МЕТОДОМ СГОРАНИЯ РАСТВОРОВ И ИХ ПРИМЕНЕНИЕ ДЛЯ ОКРУЖАЮЩЕЙ СРЕДЫ

Уникальные свойства и перспективное применение наночастиц Co_3O_4 для решения экологических проблем вызвали значительный интерес. В качестве способа эффективного производства наночастиц Co_3O_4 метод сжигания в растворе является основным направлением этого исследования, в котором также исследуются синтез, характеристика и многие применения этих частиц. Наночастицы Co_3O_4 являются привлекательным выбором для хранения энергии, чувствительных датчиков, восстановления окружающей среды и катализа из-за их замечательных особенностей, которые включают огромную площадь поверхности, пористость, плотность и магнитные свойства. Наночастицы Co_3O_4 демонстрируют потенциальные характеристики пористости, электрических характеристик и восстановления окружающей среды, такие как чувствительные датчики и очистка воды с использованием инструментов XRD, SEM, TEM, XPS и BET. Использование наночастиц Co_3O_4 в интеллектуальных технологических устройствах предлагает другой способ достижения целей устойчивого развития, таких как снижение загрязнения воздуха, замедление глобального потепления и очистка воды. Всесторонний обзор, представленный в этом обзоре, подчеркивает необходимость дальнейших исследований и исследований для полной реализации потенциала наночастиц Co_3O_4 в решении серьезных экологических проблем.

Ключевые слова: наночастицы Co_3O_4, горение раствора, пористость, чувствительные сенсоры, реабилитация окружающей среды.

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