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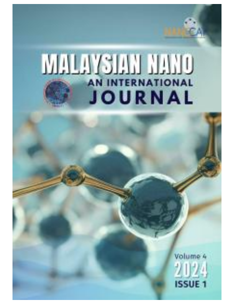


Review article

# Employing carbon nanocomposites for the removal of hazardous contaminants from aqueous solution

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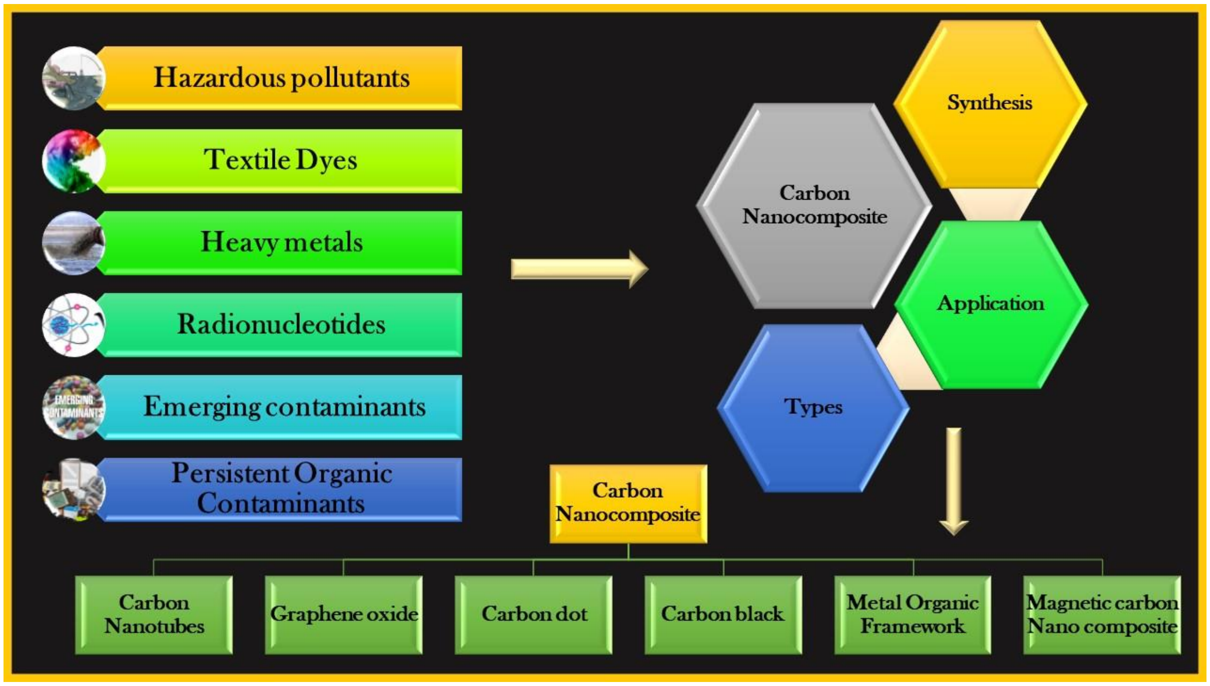
## Abstract

Carbon nanocomposites have captured the curiosity of catalysis research and adsorption studies owing to their extremely small dimensions and shape-dependent chemical and physical properties. Metal nanomaterials and materials made of carbon, including graphene and carbon nanotube-based nanocomposites, displayed exceptional catalytic properties in organic chemical reactions. Carbon nanocomposites made from biomass are a low-cost, developing, and attractive technology for the production of surface-enhanced nanocomposites. For the elimination of all harmful pollutants, including dyes, heavy metals, emerging contaminants, and persistent organic contaminants, based nanocomposites are utilised. As a result, the demand for carbon nanocomposites has been rising quickly, and the creation of new methods for preparing them deserves particular attention. This short review gives a comprehensive overview of several hazardous substances and their effects on the environment. Additionally, it examines the production, uses, and types of carbon nanocomposites as well as new developments in their capacity to remove organic contaminants from wastewater. In order to simultaneously remove contaminants from industrial effluent and advance the aims of environmentally friendly growth, future research is required. It's important to find an affordable technique to use carbon nanocomposites in wastewater treatment in large scale.

**Keywords:** Carbon nanocomposites; biomass; biochar; hazardous pollutant; adsorption

**Graphical Abstract**




## 1. Introduction

Global population explosion coupled with growing industry and urbanisation results in pollution rising at a frightening pace. The globe is experiencing a clean water deficit in emerging nations as a result of the shortage of natural water caused by industrialisation. Organic, microbial, colourants, bacterial, viral, and heavy metal (HM) pollutants are frequent contaminates. With a huge surface area, nanosorbent capacity, chemical alterations, and ease of renewal, nanotechnology is essential for cleaning up this polluted water (Arun et al. 2022). Because of its benefits of cheap preparatory cost, large surface area, pore size, and ecological stability, applied nanotechnology utilising carbon nanocomposites (CNC) has lately attracted interest. Making CNC might play a big part in the production of energy, disposal of waste, pollutant removal, and carbon storage (Barasarathi et al. 2022). The most often synthesised NC are those made of carbon, and they have high adaptability and versatility capabilities that other substances lack. Alginate is an element that occurs naturally that may be mixed and altered by attaching the active components of several materials made from carbon of interest, including graphene oxide, carbon nanotubes (CNTs), and mesoporous silicon dioxide NC, amongst others. In order to remediate the natural environment of emerging contaminants (EC), such as persistent organic pollutants (POP), toxic dyes (TD), and other ecologically hazardous contaminants (HC) of increasing concern, a variety of strong NCs have therefore been developed and implemented (Rivas-Sanchez et al. 2022).

In broad terms, NC may be broken down into three main groups: metal matrix NC, ceramic matrix NC, and polymer matrix NC. On the process of synthesis of CNC for the elimination of organic contaminants from effluent, only a few investigations were published. This brief study focuses solely on HC and its effects, biomass-derived CNC synthesis, types and uses, especially for removing HC from wastewater.

## 2. Hazardous Contaminants

All organisms need water in order to survive. Throughout the years, contamination of water has considerably increased and has become a major global issue. There are significant health and environmental hazards associated with the existence and permanence of HC such as TD, EC, HM, fertiliser, and POP, as well as the products they alter (Rathi et al. 2021).

### 2.1 Impacts of Hazardous Contaminants

Humans have always been interested in water supplies, which have now become a severe problem in all facets of human life. One of the largest global challenges is how to dispose of HC without endangering aquatic life and human health. As a result, while assessing the quality of water resources, the management of harmful contaminants is crucial (Hojjati-Najafabadi et al. 2022). The HC seriously degrades the visual appeal of aquatic areas, boosts BOD and COD (biochemical and chemical oxygen demand), hinders the process of photosynthesis hinders the development of plants, enters the food chain, provides recalcitrance and metabolism, and may encourage toxic effects, mutagenicity, and cancer risk (Lellis et al. 2019). Pulmonary harm, vomiting, nausea, diarrhoea, rash on the skin, and elevated blood pressure might occur after being exposed to HC at higher levels for a shorter period of time. Depressive disorders, problems with recall, shaking hands, lethargy, headaches, and hair loss are HC poisoning indications and symptoms. It could be challenging to understand the situation because these symptoms and indicators are commonly linked to other conditions (Zaynab et al. 2022). Consuming hazardous and harmful TD will result in serious health problems, including harm to the liver, kidneys, neurological system, and the reproductive system (Tee et al. 2022).

## 3. Carbon Nanocomposite

Scientists have been interested in CNC due of its distinct physical as well as chemical properties. These NC have a significant deal of promise for use in a variety of environmental domains, such as wastewater treatment (WWT), air pollution biological technologies, tracking, and many more (Ambika and Singh 2021).

### 3.1 Synthesis of Carbon Nanocomposite

Nanoparticle-containing CNC can be created in a variety of methods. Supports that are suitable for the CNC can be made, for instance, by deposit using the CVD process on the carbon mould and silica frameworks. The substance is then immersed in a hydrofluoric acid solution in order to dissolve the silica. In these situations, when the matrix of carbon is created in the initial stage, the NP are typically added by wet impregnation, and the resulting composites are then heated. On the other hand, the polymeric precursor approach, which is applicable to both kinds of matrix structures, silica-based and carbon-based, may be utilised to manufacture the matrix made of carbon and the NP in situ (Krolow et al. 2013). To create composites with distinctive features, magnetic CNC manufacturing is becoming more common. Nanoelectronics, catalytic processes, optical applications, biological sensors, remediation of the environment, energy, storage of hydrogen, medication delivery, imaging using magnetic resonance, and cancer diagnostics can all benefit from the consolidation of magnetic CNC with carbon-based materials. Additionally, energy-efficient thermochemical procedures like hydrothermal carbonation and pyrolysis are effective ways to create magnetic CNC with a regulated shape. These processes give chemical and structural advantages to the framework, such as a larger surface area, organised nanosizes, crystalline framework, material strength, electrical resistance, magnetic saturation occurs, and coercion (Siddiqui et al. 2018).

### 3.2 Application of Carbon Nanocomposite

CNC have sparked tremendous attention in a variety of sectors, including applications in biology, because to their extraordinary structural elements and superior electrical, mechanical, thermal, visual, and chemical properties (Xiong et al. 2018). By offering appropriate synthesis techniques, the major advancements in CNC made in recent years and the development of novel NC technology for processing have improved the functional effect of CNT and graphene composites. Battery cells, aircraft, fuel cells, the field of optics the chemical sector, power production, renewable hydrogen, space, detectors, and thermoelectric gadgets are just a few of the industries where CNC are used. the most recent developments in CNC design, production, properties, and uses, including carbon black, active carbon (AC), nanodiamonds, graphene, and CNT (Veeman et al. 2021). Super capacitors that employ CNT as electroactive elements have poorer specific capacitances than those which employ AC as a material (Ates et al. 2017).

## 4. Type of Carbon Nanocomposite

In broad terms, NC may be broken down into three main groups: metal matrix NC, ceramic matrix NC, and polymer matrix NC (Al-Mutairi et al. 2022). NC can be employed in the form of magnetic NC, Graphene oxide-based NC, carbon dot, carbon black, metal organic framework (MOF) NC, CNT and so on.

### 4.1 Carbon Nanotubes

In a variety of applications, from safety to related to energy devices, CNTs have been regarded as a potential technology. CNT employment and its applications have been hampered by their limited solubility in aqueous and organic liquids (Norizan et al. 2020). CNTs are a group of carbon-based combinations with unique features that make them beneficial substances for use in a variety of nanotechnology applications, including optical and therapeutic devices, electrical devices, and medical applications (Anzar et al. 2020). Table 1 gives the overview of various application of carbon nanotubes. Durability and excellent electrical and thermal conductivity are just a few of their standout qualities. Their singularity can be linked to the robust and high extreme aspect ratio bonding arrangement that exists among the atoms (Mohanta et al. 2019). The number of sidewalls available and how they are distributed spatially are used to categorise CNTs as single-walled or multi-walled CNT. The use of CNTs to enhance the functionality of several items, particularly in the field of healthcare, has resulted in professional and public access to these NP. Therefore, it becomes extremely important to examine the problems related to the poisoning of CNTs and identify the most effective solutions to those problems (Garg et al. 2021).

**Table 1:** Various application of carbon nanotubes

| Carbon Nanotube | Application | Reference |
|---|---|---|
| MXene-like CNT | Removal of tetracycline hydrochloride | Zhang et al. 2022 |
| Magnetic and porous regenerated cellulose CNT $Fe_3O_4$ nanoparticles (NP) | Removal of bisphenol A | Dong et al. 2022a |
| Copper–nickel ferrite NP loaded onto multi-walled CNT | Removal of acid blue 113 | Al-Musawi et al. 2022 |
| Polyaniline and multi-walled CNT | Removal of Methylene blue | Ardani et al. 2022 |
| Polyaniline and multi-walled CNT | Removal of Rhodamine B | Ardani et al. 2022 |

| | | |
|---|---|---|
| Polyaniline and multi-walled CNT | Removal of Methyl Orange | Ardani et al. 2022 |
| Nitrogen-doped multi-walled CNT | Removal of phenol | Liu et al. 2022 |
| Multiwalled CNT with bovine plasma | Removal of copper | Martins et al. 2022 |
| Novel iron carbide loaded N-doped CNT | Removal of copper | Liu et al. 2023 |
| Pristine CNT | Removal of ciprofloxacin | Elamin et al. 2023 |
| Pristine CNT | Removal of indigo carmine | Elamin et al. 2023 |
| $Fe_2O_3$ CNT | Removal of tetracycline | Ma et al. 2023 |
| Fe/$Al_2O_3$- plastic derived CNT | Removal of atenolol | Ribeiro et al. 2022 |
| Fe/$Al_2O_3$- plastic derived CNT | Removal of metoprolol | Ribeiro et al. 2022 |
| Fe/$Al_2O_3$- plastic derived CNT | Removal of venlafaxine | Ribeiro et al. 2022 |
| Fe/$Al_2O_3$- plastic derived CNT | Removal of citalopram | Ribeiro et al. 2022 |
| Molybdenum oxide NP CNT | Removal of dibenzothiophene | Alwan 2022 |
| N-doped CNT-confined FeMn NP | Removal of 4-chlorophenol | Duan et al. 2022 |
| Zn-Al layered double hydroxide anchored on multiwalled CNT | Removal of Congo red dye | Zong et al. 2022 |
| Humic acid multi-walled CNT | Removal of methylene blue | Dong et al. 2022 |
| Humic acid multi-walled CNT | Removal of Reactive blue 19 | Dong et al. 2022 |
| Mg/Fe-N CNT | Removal of ciprofloxacin | Zheng et al. 2023 |
| Mg/Fe-N CNT | Removal of bisphenol A | Zheng et al. 2023 |

| | | |
|---|---|---|
| Mg/Fe-N CNT | Removal of Tetrabromobisphenol A | Zheng et al. 2023 |
| Mg/Fe-N CNT | Removal of Triclosan | Zheng et al. 2023 |
| Mg/Fe-N CNT | Removal of tetracycline | Zheng et al. 2023 |
| Mg/Fe-N CNT | Removal of Rhodamine B | Zheng et al. 2023 |
| Layered double hydroxides on CNT | Removal of tetracycline | Xia et al. 2022 |
| g-$C_3N_4$/α-$Bi_2O_3$/MWCNT | Removal of methylene blue | Palanisamy et al. 2022 |
| g-$C_3N_4$/α-$Bi_2O_3$/MWCNT | Removal of Rhodamine B | Palanisamy et al. 2022 |
| CNT modified with tetrahydrofuran | Removal of copper | Ghanavati et al. 2022 |
| CNTs-driven periodate | Removal of phenol | Peng et al. 2023 |

### 4.2 Graphene Oxide

Graphene has been changed to take the shape of GO. Like graphene, GO has attracted a lot of attention due to its numerous industrial potentials. Conjugated polymers (CP), which have a conductive backbone, are renowned organic compounds. Due to π-conjugation throughout the primary chain, these CP have a semi-conducting property. It has been modified and doped to increase the CP's electrical mobility. The NC of the CP has been described in conjunction with GO and nanocarbon nanofillers (Kausar 2021). Magnetic graphene oxide (MGO)-based NC have exceptional magnetic features, a large amount of specific surface area, surface sites that are active, high chemical stability, customizable form and dimensions, and are simple to modify or functionalize. These are only a few of the distinctive physical and chemical features of MGO-based NC. MGO have been extensively used in the elimination of HM, radioactive substances, and TD from aquatic systems and are now gaining a lot of interest as a consequence of their versatile features, cost-effectiveness, and magnetization capabilities (Lingamdinne et al. 2019). Figure 1 depicts the synthesis technique of graphene oxide from graphite.

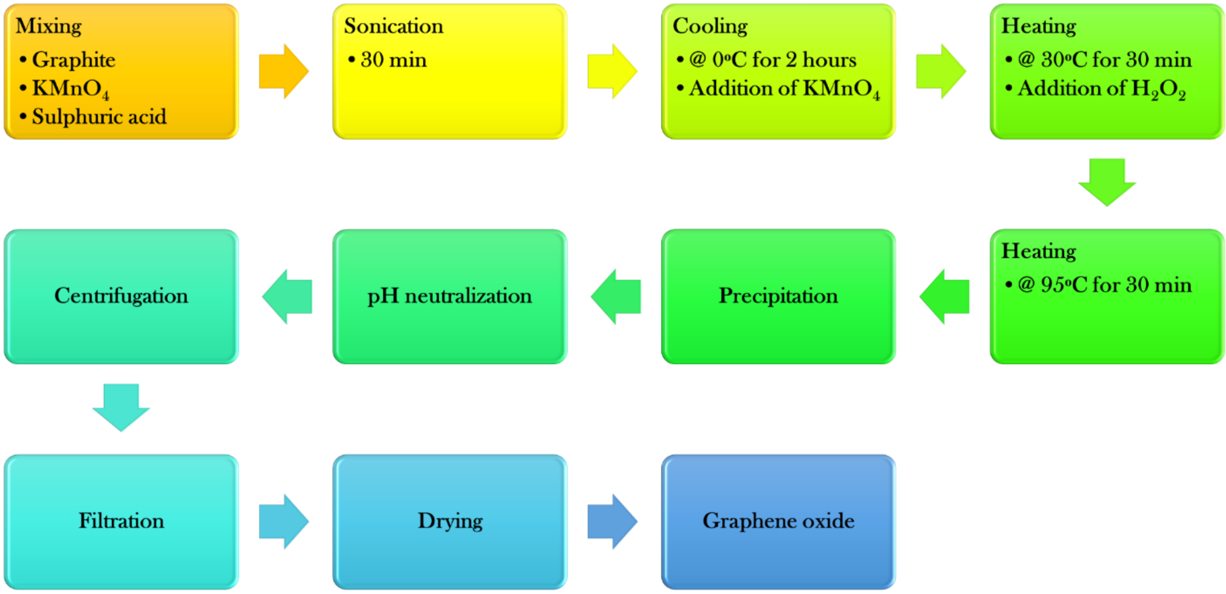



**Figure 1:** Synthesis technique of graphene oxide from graphite

Widespread attention has been generated by GO-based adsorbents as efficient adsorption agents for removing HM from the atmosphere (Thangamani et al. 2021). However, in numerous instances, surface alteration is required since pure GO could not work as well in certain situations, including the adsorption of HM ions. As a result, research into the alteration of GO with different metals and non-metals is underway in the field of carbon-based materials. An affordable and sustainable method of altering GO for ecological uses like HM adsorption is the use of organic compounds (Sherlala et al. 2018).

### 4.3 Carbon Dot

A unique class of multipurpose carbon nanoparticles called carbon dots (CD) has the capacity to revolutionise a number of key industries that assist the shift to a green bioeconomy. Tunable photoelectric and fluorescent capabilities, low toxicology, strong biological compatibility, biological activity, and improved solubility in water are only a few of the appealing characteristics of CD. Different techniques and predecessors have been used to create CD (Feng et al. 2021). A current research focus and a requirement for large-scale manufacturing and utilisation is the ability to scale-up the production of CD using environmentally friendly chemical principles. Adding CD to the matrix of polymers is another new field of study with a broad range of possible applications. With this method, more useful functions may be added, and reuse and handling are made simple. The necessity for lightweight electronics along with additional materials or devices is highlighted by the recent focus on the storage and conversion of energy as well as modifications to the lifestyles. In light of the above, MXene-CD NC may prove to be ideal for use as electrocatalysts in fuel cells, materials for electrodes in metal-ion rechargeable batteries, supercapacitors, solar power plants, and photodetectors, to mention a few (Elemike et al. 2022). Because of their optoelectronic characteristics and wide range of band modification upon surface redesign, CD in particular have drawn considerable interest in the creation of devices for biomedical use (Pathak et al. 2023).

### 4.4 Carbon Black

One of the most widely manufactured carbon nanostructured matter compounds is carbon black (CB), and over 70% of it is employed as a colouring agent and reinforcement component in rubber and plastics. Other applications of CB, such as green energy harvest and capturing carbon, are also of interest, according to recent research studies (Khodabakhshi et al. 2020). The effective commercial application of rubber in numerous fields depends on the addition of CB particulates, and the physical strengthening impact of CB in rubber has been researched for almost a century (Ismail et al. 2013). Despite decades of research, it is still unclear what causes elastomers to become stiffer when CB nanoparticles of nanoscale size are added. It is debatable whether the contacts among the chains of polymers and CB edges are just physical adsorption or if the process of blending and curing the CB-filled rubber compounds also introduces certain chemical linkages among polymer and nanoparticle (Robertson and Hardman 2021).

### 4.5 MOF Carbon Nanocomposite

One of the most rapidly expanding disciplines in the fields of material science and chemistry over the past 20 years is MOF, also referred to as coordination polymer networks, which is a group of highly attractive porous crystalline inorganic-organic hybrid substances (Manoj et al. 2022). In addition to combining the respective positive traits of the metal ions and organic ligands, MOF frequently exhibit special qualities that go beyond what is expected from a straightforward combination of the constituents. MOF are of great interest in a variety of applications, including storing gases, detecting, segregation, regulated guest release, and catalytic processes, because of their distinctive properties, such as changeable organic bonds, adjustable coordination space, and customizable interior surfaces (Liu et al. 2019). Because of their distinctive features that result from MOF are used in a variety of biological applications (Giliopoulos et al. 2020). Table 2 gives the overview of various application of MOF-CNC. By combining MOFs with substances that provide a higher degree of stability, which is difficult to obtain for the organic structure, their qualities can be increased yet more, expanding the range of applications for which they can be used. Because there are several synthetic options for element incorporation and because crystalline or amorphous inorganic elements offer a variety of beneficial properties, MOFs combined with inorganic substances are of particular interest among the final composite nanomaterials. By combining MOFs with inorganic substances like zeolites, silica, and metal oxides, it is possible to tailor the physical and chemical characteristics of the parent substances in order to create composites with a wide range of practical uses (Rani et al. 2022). Fig. 2 represents the Metal organic framework.

**Table 2:** Various application of MOF carbon nanocomposite

| MOF Carbon Nanocomposite | Application | Reference |
|---|---|---|
| Co-doped MOF | Removal of Rhodamine B | Li et al. 2022 |
| Zr-based MOF | Removal of mercury | Wu et al. 2019 |
| Zr-based MOF | Removal of cadmium | Wu et al. 2019 |
| Zr-based MOF | Removal of lead | Wu et al. 2019 |
| Zr-based MOF | Removal of copper | Wu et al. 2019 |
| Zr-based MOF | Removal of cobalt | Wu et al. 2019 |
| Zr-based MOF | Removal of nickel | Wu et al. 2019 |
| Zr-based MOF | Removal of Zinc | Wu et al. 2019 |
| Zr-based MOF | Removal of Iron | Wu et al. 2019 |
| Zr-based MOF | Removal of Manganese | Wu et al. 2019 |
| $((ZnCl_2)_3(L)_2\cdot DMF)_n$ MOF | Removal of Tetracycline | Li et al. 2020 |
| MOF Derived Co/C Yolk–Shell | Removal of bisphenol A | Zhang et al. 2020 |
| Zeolitic imidazolate MOF-67 | Removal of Basic Red 18 | Mahmoodi et al. 2019b |
| Zeolitic imidazolate MOF-67 | Removal of Copper | Mahmoodi et al. 2019b |
| Zirconium MOF | Removal of rhodamine 6G | Guo et al. 2019a |
| Zirconium MOF | Removal of propranolol | Guo et al. 2019a |
| Zirconium MOF | Removal of bisphenol A | Guo et al. 2019a |
| Cu@Co-MOF-71 | Removal of ciprofloxacin | Chen et al. 2022 |
| UiO-66-$NH_2$ MOF | Removal of methyl orange | Hashem et al. 2019 |
| UiO-66-$NH_2$ MOF | Removal of Chromium | Hashem et al. 2019 |
| MOF MIL-100(Fe) | Removal of amaranth red | Zhao et al. 2019 |
| MOF MIL-100(Fe) | Removal of vanillic aldehyde | Zhao et al. 2019 |
| GO-Cu-MOF | Removal of Methylene blue | Firouzjaei et al. 2020 |
| ($NH_2$-CNT/$Fe_2O_3$)-zeolitic imidazolate MOF | Removal of Malachite Green | Mahmoodi et al. 2019 |

| | | |
|---|---|---|
| ($NH_2$-CNT/$Fe_2O_3$)-zeolitic imidazolate MOF | Removal of Rhodamine B | Mahmoodi et al. 2019 |
| Chromium-based MOF | Removal of Acid Green 25 | Mahmoodi et al. 2019a |
| Chromium-based MOF | Removal of Reactive Yellow 186 | Mahmoodi et al. 2019a |

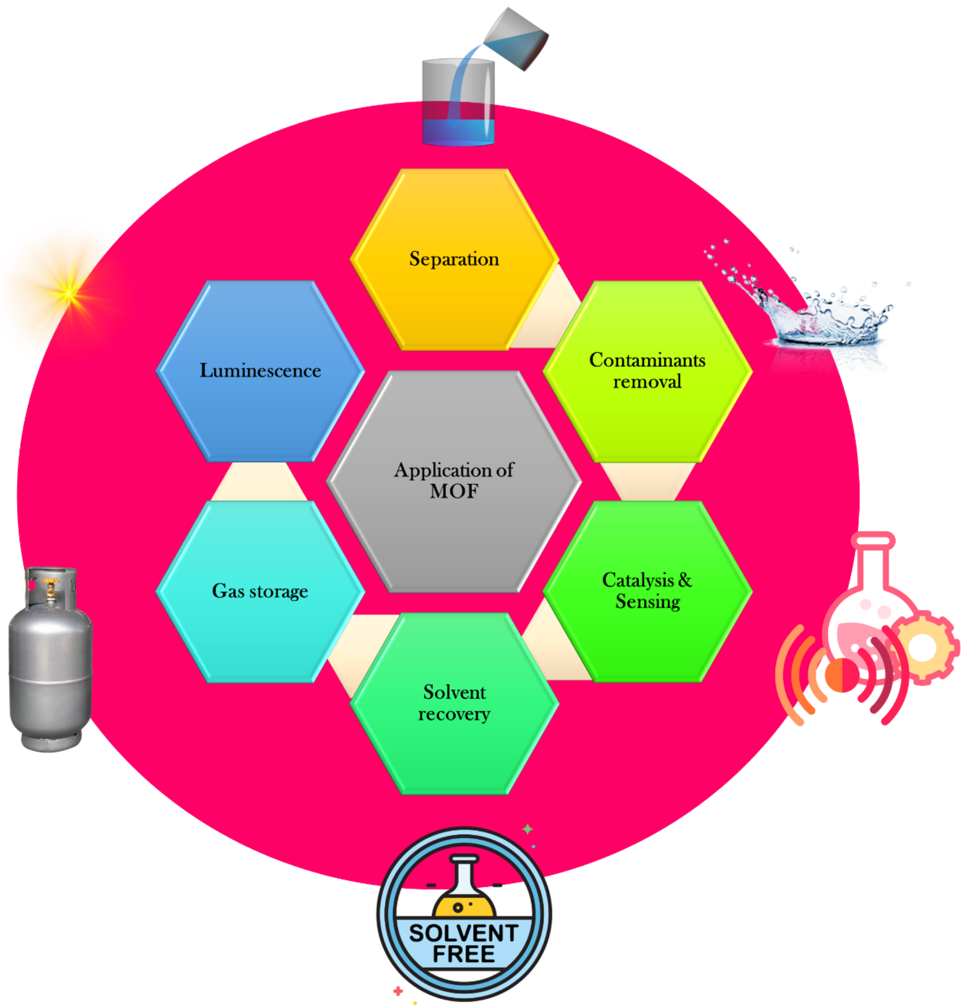



**Figure 2:** Employment of Metal organic framework in different fields

## 4.6 Magnetic Carbon Nanocomposite

The academic and technological applications of magnetic NC with clearly defined mesoporous layouts, forms, and customised characteristics are enormous (Liu et al. 2011). The topic of magnetic NC includes a wide range of different substances and combinations of materials as well as a wide range of uses from technological to biological ones (Behrens and Appel 2016). Table 3 gives the overview of various application of magnetic-CNC. Due to the magnetism, they possess as well as their incorporation of special qualities of organic and inorganic components, these composite magnetic NC have acquired significant uses in WWT. The elimination of various types of HC from waterbodies is better suited to materials that are carbon- and polymer-related magnetised NC. In order to create these NC, a variety of techniques may be used, including filling, pulse-laser radiation treatment, grinding with balls, and electro-spinning (Mehmood et al. 2021).

**Table 3:** Various application of magnetic carbon nanocomposite

| Magnetic Carbon Nanocomposite | Application | Reference |
|---|---|---|
| Magnetic composites CNT/$MnFe_2O_4$ | Removal of Tetracycline | Foroutan et al. 2021 |
| Magnetic composites CNT/ β-cyclodextrin/$MnFe_2O_4$ | Removal of Tetracycline | Foroutan et al. 2021 |
| Magnetic carbon supported Prussian blue NC | Removal of 2,4-dichlorophenol | Guo et al. 2019 |
| $Fe_3O_4$-$SiO_2$-Dimethoxydiphenylsilane NC | Removal of phenanthrene | Wei et al. 2022 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Heptachlor | Ismael et al. 2020 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Aldrine | |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Heptachlor epoxide | Ismael et al. 2020 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Endosulfan | Ismael et al. 2020 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Dieldrine | Ismael et al. 2020 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Endrine | Ismael et al. 2020 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Endrine aldehyde | Ismael et al. 2020 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Endosulfane sulfate | Ismael et al. 2020 |
| Magnetic $TiO_2$/GO/$CuFe_2O_4$ NC | Removal of Methoxychlor | Ismael et al. 2020 |
| Magnetic carbon aerogel | Removal of bisphenol-A | Ahamad et al. 2019 |
| $CoFe_2O_4$ magnetic NC | Removal of methylene blue dye | Foroutan et al. 2021 |
| $CoFe_2O_4$ magnetic NC | Removal of crystal violet dye | Foroutan et al. 2021 |
| $CoFe_2O_4$ magnetic NC | Removal of methyl violet dye | Foroutan et al. 2021 |
| PPy-$Fe_3O_4$-SW nano-composite | Removal of Methylene Blue | Sarojini et al. 2022 |

## 5. Conclusion and Future Perspective

In this review a comprehensive overview of several hazardous substances and their effects on the environment has been explored. Additionally, it examines the production, uses, and types of carbon nanocomposites as well as new developments in their capacity to remove organic contaminants from wastewater. Metal NP-assisted CNC have been seen to play a significant role in a wide range of possible implications for research and technology. Engineered nanomaterials made from carbon are increasingly in demand for commercial uses in the fields of cutting-edge technology, healthcare, environmental protection, and farming. The unique characteristics of carbon-based nanotechnology have attracted the attention of researchers and entrepreneurs, which has sparked the development of novel methods for essential production in industry.

It has proven effective to use CNT to increase the material's tensile strength. Because of their versatility, inexpensiveness, low environmental impact, and outstanding biological compatibility, CD hold a lot of potential as the foundation for the next wave of NC materials. Creating novel CNC adsorbents that are risk-free, effective, and inexpensive is still difficult. To increase their usefulness to the processing of water and wastewater, future research should investigate innovative characteristics of carbon NP, such as chemical stabilisation and surface modifications. To determine future prospects for this developing field's further growth, the difficulties associated in the creation of these innovative nanoadsorbents for the purification of effluents have also been addressed.

**Declarations**

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Availability of data and material**

The data and material will be available on reasonable request.

**Competing interest**

The authors declare no competing interests.

**Conflicts of interest**

The authors declare that they have no conflict of interest.

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