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Chapter

Recent Development of Graphitic Carbon Nitride-Based Photocatalyst for Environmental Pollution Remediation

Mohamad Fakhrul Ridhwan Samsudin, Nurfatien Bacho and Suriati Sufian

Abstract

Globalization today has helped fuel the global socioeconomic growth of the world and reshaping the growth of the industries. While the development had been remarkable, the rapid rise of industrialization had provoked the sustainable chain of diversity which is reflected by rising pollution level, particularly on the water pollution. On account of the cutting edge of water security issue, engineering photocatalytic material remains crucial in finding new ways to combat the challenge of water pollution through photocatalytic pollutants degradation while at the same time acts as the frontlines for energy conversion and environmental protection. To date, graphitic carbon nitride, g-C₃N₄ has emerged as a promising material of interest in photocatalytic application due to its appealing characteristics such as excellent optical properties and high physiochemical and thermal stability. This chapter will comprehensively discuss an insight into the most recent progress in synthesis, properties and the photocatalytic application of g-C₃N₄, particularly in environmental pollution remediation. Special emphasis is also placed on the most recent strategies for enhancing the photocatalytic performance of the g-C₃N₄ photocatalyst. Finally, the future directions and perspectives will be presented.

Keywords: graphitic carbon nitride, photocatalyst, degradation, nanomaterial

1. Introduction

The exponential growth of the industries over the past decade had exerted substantial pressure on sustainability, mainly on the pillars of the environment. While the gap towards an improved well-being brings many intended benefits. The environmental sustainability challenge is also growing at a large scale and complexity, resulting in severe environmental impacts including water pollutions. Within this context, the rise of industrialization alongside with the rapid growth of the global population has been intimately linked with a higher generation of wastewater [1–3]. The statistical glance from United Nations World Water Assessment Programme (2003) has reported that around 2 million tons of industrial sewage and agricultural waste have been discharged into the water bodies every day. Based on
the report by the WHO/UNICEF Joint Monitoring Programme, the current statistics reveal that there are approximately 2.1 billion people who are lack access to clean drinking water. Another report by UNESCO (2017) claims that approximately 80% of the wastewater flow is discharged into the ecosystem without any treatment thus contaminating a large portion of the water bodies. In this sense, the excessive release of anthropogenic pollutants originated from industrial use such as the phenolic compound, heavy metals and dyes had resulted in a deterioration in water quality and pose harmful effect on the living organism, which further emphasizes the need to tackle the water pollution issue [4–6].

Engineering photocatalytic material had emerged as a promising technology to bridge the gap between global energy challenge and environmental remediation. Since the pioneering discovery of photocatalytic water splitting by Fujishima and Honda in 1972, photocatalytic material has attracted interdisciplinary attention due to its diverse potential in various discipline such as solar energy conversion, photocatalytic water splitting for hydrogen production and carbon dioxide reduction, organic pollutants degradation and synthesis of organic compounds [7–9]. For the wastewater treatment field, photocatalytic degradation of pollutants is favorable over the conventional method due to its several advantages. This technique does not require non-renewable energy consumption as it exploits the sustainable solar energy [10–12]. Applicable both for gaseous and aqueous treatment, photocatalysis technology reportedly can degrade a wide range of pollutants and toxic compounds without causing any secondary pollutants. Moreover, the photocatalyst can be easily synthesized through various methods from an abundant readily available precursor. The whole process is not only simple to conduct, low in cost and require a relatively short process time, making the method sustainable for wastewater purification in a large scale application.

At presents, there are a various ongoing effort for the development of the sustainable photocatalytic system, with the focused centered on the development of noble metal-free photocatalyst as TiO$_2$, g-C$_3$N$_4$, BiVO$_4$, ZnO, and carbonaceous materials [12–17]. Among these photocatalysts, graphitic carbon nitride (g-C$_3$N$_4$) has elicited significant interest as the next generation of the photocatalyst in engineering photocatalytic field for environmental pollutants degradation due to its excellent physiochemical properties [18–21]. The g-C$_3$N$_4$ is novel, metal-free photocatalyst with good light absorption properties owing to its medium band-gap energy of 2.7 eV [19, 22, 23]. The polymeric nature of this conjugated materials allows for facile modification of the photocatalyst to improve its optical properties besides permit multiple excitations from absorption of a single photon, both of which are favorable for efficient pollutants degradation. However, the practical application of g-C$_3$N$_4$ is still hindered by some of its individual properties such as low visible light utilization, the high recombination rate of photogenerated electron–hole pairs and slow electron transfer which lead to lower photocatalytic performance [22]. Hence, various strategies have been adopted such as energy band engineering, copolymerization with nitrogen precursor and development of heterostructure system in order to overcome the individual drawbacks of pristine g-C$_3$N$_4$ [24–26].

In recognition of the great potential of g-C$_3$N$_4$ as a promising visible light driven photocatalyst, this chapter is aiming to provide an overview on the most recent related studies on the development of g-C$_3$N$_4$ photocatalyst in the environmental pollution remediation. The history and basic principle of photocatalyst system are well explained in order to promote better understanding on the g-C$_3$N$_4$. Afterward, the fundamental properties of g-C$_3$N$_4$ and the synthesizing techniques are briefly summarized. Next, the current strategies to enhance the
overall performance of g-C\(_3\)N\(_4\) photocatalyst are explained. Subsequently, the current perspective and future directions of the g-C\(_3\)N\(_4\) photocatalyst are included in this chapter.

2. General overview on g-C\(_3\)N\(_4\) photocatalyst

The history of engineering photocatalytic material could be traced back to 1972, where photoelectrochemical splitting of water in the presence of TiO\(_2\) and ultraviolet light by Fujishima and Honda had served as the starting point for photocatalytic reaction [27]. Since then, numerous semiconductor-based photocatalysts have been investigated in an attempt to produce a robust photocatalyst for an efficient novel photocatalytic system. Among them, TiO\(_2\), BiVO\(_4\), Fe\(_2\)O\(_3\) and ZnO had been identified as a potential promising photocatalytic material [28–30]. Although Titanium oxide (TiO\(_2\)) had dominated the photocatalytic arena, this photocatalyst suffers from its negative characteristics which hinder the practical exploitation of this material for large scale application [8, 9]. Hence, other potential materials have been tested and explored in the search for robust photocatalyst for large scale application. Among them, g-C\(_3\)N\(_4\) had emerged as one of the promising material and become the new research hotspot for various scientific application owing to its excellent features.

2.1 Introduction to g-C\(_3\)N\(_4\) photocatalyst

Graphitic carbon nitride is one of the oldest artificial polymer reported back in 1834. Structurally analogous to graphene, this conjugated polymer is a novel, metal-free with a medium band gap of 2.7 eV [31]. Generally, there are several allotropes of C\(_3\)N\(_4\) such as α-C\(_3\)N\(_4\), β-C\(_3\)N\(_4\), pseudocubic C\(_3\)N\(_4\), cubic C\(_3\)N\(_4\), g-h triazine and g-C\(_3\)N\(_4\). However, g-C\(_3\)N\(_4\) is considered the most stable form of C\(_3\)N\(_4\) under ambient conditions. Figure 1 illustrates the basic tectonic units to establish the allotropes of the g-C\(_3\)N\(_4\) photocatalyst. It was reported that the tri-s-triazine-based g-C\(_3\)N\(_4\) photocatalyst was the most stable phases of C\(_3\)N\(_4\) at ambient conditions. This postulation was further verified by Kroke et al. [32] with their first-principles density functional theory (DFT) calculations. Meanwhile, only the pseudocubic and g-h triazine phases have direct band gaps while the other phases have indirect band gap energies [32].

![Figure 1](image-url)

Figure 1. The basic tectonic units for g-C\(_3\)N\(_4\) photocatalyst (a) triazine and (b) tri-s-triazine (heptazine) structures. (Adapted with permission from Ref. [22]).
Carbon nitride, $C_3N_4$, is not new at all, and it is considered one of the oldest reported artificial polymers in the scientific literature [26]. Figure 2 shows the historical development of g-$C_3N_4$ in photocatalysis arena. This g-$C_3N_4$ was first reported by Berzelius and Liebig in the year 1834 and named as melon [33]. Although it was first discovered back in 1834, the material is not exploited until 2009 when Wang et al. first reported the utilization of this material in the photocatalysis field [26]. Since then, a lot of researchers started to unravel the promising potential of the g-$C_3N_4$ photocatalyst in a wide range of different photocatalytic applications. Nevertheless, owing to the limited experimental data, there is a prevailing discussion about the actual existence of a graphitic material with idealized composition $C_3N_4$ and possible structure models for g-$C_3N_4$ photocatalyst. Gratifyingly, due to the similar structure with graphite, triazine ($C_3N_4$) had been put forward as the elementary block of g-$C_3N_4$. Moreover, tri-s-triazine rings also shown promises to be energetically favored with respect to the triazine-based modification as the tri-s-triazine rings are cross-linked by trigonal nitrogen atoms [34]. Ideally, the condensed g-$C_3N_4$ consists of only carbon and nitrogen atoms with a C/N molar ratio of 0.75. Nonetheless, there is no perfectly condensed g-$C_3N_4$ was reported and they are as-grown polymer materials that are not single crystals. Hence, the g-$C_3N_4$ photocatalyst can be seen as a family of layered graphitic carbon nitride compounds with a C/N ratio close to 0.75.

### 2.2 Synthesis method for the development of g-$C_3N_4$ photocatalyst

Since the potential of carbon nitride in the photocatalysis arena had been known, various synthesis method and technique had been instigated such as chemical vapor deposition, sonochemical, solvothermal, and thermal annealing of nitrogen-rich precursor [24, 32, 33]. Following the variation in synthesis technique, the various compound can be used as the precursor such as melamine, cyanamide, dicyanamide, urea, and thiourea. However, thermal condensation of nitrogen-rich precursor has emerged as the most attractive methods due to its simplicity and use of cheap, earth-abundant precursors.

In the first reported work by Wang et al. [35], cyanamide was used as the starting precursor of g-$C_3N_4$. It was found that the cyanamide molecules were condensed to dicyanamide and melamine at temperatures of ca. 203 and 234°C. Next, the ammonia was removed via condensation process, resulting in the formation of melamine-based products at the temperature around 335°C. When the temperature was heated up to ca. 390°C, the tri-s-triazine units was formed via rearrangements of melamine. Finally, the polymeric g-$C_3N_4$ photocatalyst was
formed at ca. 520°C through the further condensation of the unit. Nevertheless, the overheating of the sample over 700°C resulted in the disappearance of g-C\textsubscript{3}N\textsubscript{4} to “residue-free” through the production of nitrogen and cyano fragments. With respect to the experimental approaches, the reaction mechanism of the combined polyaddition and polycondensation process was further verified by the ab initio calculations using a plane wave basis set with a 550 eV energy cutoff [34]. Based on the calculations, Figure 3 illustrates the cohesive energy of the molecules increased following the polyaddition pathway, confirming that melamine was produced upon heating the cyanamide [22].

Meanwhile, the most commonly used precursor in thermal condensation method includes those with nitrogen-rich and oxygen-free compounds, which contain the required C-N structure. The compounds with pre-bonded C-N core structure such as melamine, cyanamide, dicyanamide, urea and thiourea are among the commonly used precursors for the synthesis of g-C3N4. In addition to that, triazine and heptazine derivatives also had been tested as a precursor. For example, Mo et al. [34] prepared the g-C\textsubscript{3}N\textsubscript{4} photocatalyst via manipulating the calcination temperature on the morphological structure of melamine. It was found that the g-C\textsubscript{3}N\textsubscript{4} photocatalyst can only be formed when the calcination temperature above 500°C, evidently from the XRD analysis. Furthermore, it was found that the absorption band edge was red shifted along with the change of color from light yellow to dark orange, indicating the enhanced visible light absorption was obtained for samples with increasing calcination temperatures.

On the other hand, Dong et al. [36] prepared the g-C\textsubscript{3}N\textsubscript{4} using urea via a facile template-free. Their group studies the effects of pyrolysis time on the microstructure and activity of g-C\textsubscript{3}N\textsubscript{4} photocatalyst. They suggested that the surface areas of the photocatalyst can be significantly increased by just prolonging the pyrolysis time to 240 minutes at under 550°C. They claimed that the surface area of g-C\textsubscript{3}N\textsubscript{4} photocatalyst prepared via this method is higher than g-C\textsubscript{3}N\textsubscript{4} photocatalyst prepared via templating method. Similarly, Chen et al. [37] prepared g-C\textsubscript{3}N\textsubscript{4} photocatalyst by pyrolyzing urea in a muffle furnace at 550°C for 2 hours with a heating rate of 5°C/min. Meanwhile, Yang et al. [38] prepared ultrathin g-C\textsubscript{3}N\textsubscript{4} photocatalyst nanosheets via thermal exfoliation of bulk urea-derived g-C\textsubscript{3}N\textsubscript{4} under an argon atmosphere. In addition, Figure 4 summarizes the synthesis process of g-C\textsubscript{3}N\textsubscript{4} photocatalyst by thermal polymerization of different precursors.

Figure 3.
Calculated energy diagram for the development of C\textsubscript{3}N\textsubscript{4} using cyanamide as the precursor. Cyanamide was condensed to melamine. Further condensation proceeded by a triazine route (dash-dot line) or tri-s-triazine (dashed line). (Adapted with permission from Ref. [33]).
2.3 Fundamental properties of g-C\textsubscript{3}N\textsubscript{4} photocatalyst

Graphitic carbon nitride possesses an excellent physical, chemical and mechanical properties, giving a reason on why researchers are eager into the science of nanotechnology of g-C\textsubscript{3}N\textsubscript{4}. This compound possesses excellent visible light absorption than most of the metal oxide photocatalyst owing to its mild band gap energy. Given its π-conjugated properties, g-C\textsubscript{3}N\textsubscript{4} can act as an electron sink, leading to suppression of recombination of photo excited charge carriers. Moreover, the polymeric nature of this material allows for multiple excitations from absorption of a single photon, leading to an efficient generation of the reactive species responsible for pollutant degradation. In addition, g-C\textsubscript{3}N\textsubscript{4} possesses high resistance to thermal and chemical environment, as well as too acidic and basic media, making it as a stable material.

Furthermore, Wang et al. [39] performed a density functional theory (DFT) calculations in order to gain insight into the electronic structure of g-C\textsubscript{3}N\textsubscript{4} photocatalyst (as shown in Figure 5). They reported that the valence band and conduction band are mainly composed of the nitrogen p\textsubscript{z} orbitals and carbon p\textsubscript{z} orbitals, respectively. The light illumination excited the electrons and holes for the oxidation and reduction process to occur independently in the nitrogen atoms and carbon atoms. Congruously, the g-C\textsubscript{3}N\textsubscript{4} photocatalyst has a specific microstructure, with surface termination as defects and nitrogen atoms for electron localization or anchoring inorganic/organic functional motifs as the active sites [32]. However, the practical application of g-C\textsubscript{3}N\textsubscript{4} is still hindered by some of its undesirable properties which lead to lower photocatalytic performance. The individual structure of g-C\textsubscript{3}N\textsubscript{4} has low specific surface area and quantum efficiency, which limit the sorption capacity of the photocatalyst [26]. This photocatalyst also suffers from high recombination rate of the photogenerated electron–hole pairs.

2.4 Photocatalytic principles and mechanism over g-C\textsubscript{3}N\textsubscript{4} photocatalyst

Photocatalyst can be described as a combination of catalysis and photochemistry in which absorption of photon energy from light via catalyst is the
key towards photoreaction process. In this system, photon energy is required to activate the photocatalyst which make this photocatalyst system to be one of the frontier renewable energy technology in which it can utilize the solar energy. The g-C$_3$N$_4$ photocatalyst has a small band gap energy around 2.6–2.7 eV which falls within the visible-light region [25]. It is estimated that the valence band (VB) and the conduction band (CB) of the g-C$_3$N$_4$ photocatalyst are 1.56 and 1.09 eV, respectively [40].

Initially, the g-C$_3$N$_4$ photocatalyst will absorb photon energy with an energy equivalent or greater than its band gap energy, causing an electron ($e^-$) in the valence band (VB) to be excited and migrate to the conduction band (CB).

$$g - C_3N_4 + h\nu \rightarrow e^-_{CB}(g - C_3N_4) + h^+_{VB}(g - C_3N_4) \quad (1)$$

Then, the electron will be excited and leave photogenerated holes ($h^+$) in the valence band. The photogenerated holes and photoexcited electrons will migrate to the surface of the photocatalyst and trapped there. The photogenerated holes then react with adsorbed water to produce strong oxidizing $\cdot$OH radicals whereas the photoexcited electrons react with adsorbed oxygen to generate $\cdot$O$_2^-$ radicals [41].

$$e^-_{CB}(g - C_3N_4) + O_2 \rightarrow \cdot O_2^- \quad (2)$$

$$h^+_{VB}(g - C_3N_4) + OH^- \rightarrow \cdot OH \quad (3)$$

The formation of these radicals will further react with recalcitrant pollutant and subsequently degraded the recalcitrant pollutant.
• $\text{O}_2^- + \text{recalcitrant pollutants} \rightarrow \text{degradation of pollutant}$ (4)
• $\text{OH} + \text{recalcitrant pollutants} \rightarrow \text{degradation of pollutant}$ (5)

2.5 Strategies to improve g-C$_3$N$_4$ photocatalytic performance

In order to overcome the individual drawback of pure g-C$_3$N$_4$, many attempts have been made to improve the photocatalytic capability including surface modification of the photocatalyst structure. Generally, the surface modification aims to improve the photocatalyst specific surface area, charge separation and optical. There are currently five modification techniques which have been investigated including the introduction of heteroatoms (i.e. metals and non-metals) within g-C$_3$N$_4$ framework, noble metal deposition, hybridizing g-C$_3$N$_4$ with carbon nanomaterials and coupling g-C$_3$N$_4$ with a photocatalyst. The principle, advantages and disadvantages of each technique are summarized in Table 1.

On the other hand, the development of the heterostructure photocatalyst via the introduction of additional compounds into the g-C$_3$N$_4$ network is one of the most promising strategies to enhance the overall catalytic performance of g-C$_3$N$_4$ photocatalyst [22]. In general, the g-C$_3$N$_4$-based heterostructure can be developed by coupling the g-C$_3$N$_4$ with other types of photocatalyst as co-catalyst. The formation of the heterostructure with suitable band position would suppress the recombination rate of the photogenerated electron–hole pairs, which lead to higher

| Modification method | Principle | Advantages | Disadvantages |
|---------------------|-----------|------------|---------------|
| Metal doping        | Doping of various metallic species such as the alkali metals, rare earth metals and noble metals into g-C$_3$N$_4$ | Bandgap narrowing, surface area improvement, charge separation and fine-tuning the band structure | Can often cause secondary pollution due to leaching of the metal ions |
| Non-metal doping    | Doping g-C$_3$N$_4$ with non-metals | No secondary pollution, improve visible light absorption and charge separation | Non-metal species does not take part in charge transportation hence recombination centers are formed |
| Noble metal deposition | Deposition of noble metal nanoparticles such as Cu, Pt, Au and Pd on g-C$_3$N$_4$ | Metal content positively influence the photocatalytic activity until the optimum loading is reached | Beyond the optimum metal loading, the excess metal ions act as recombination centers for the electron/hole pairs |
| Hybridizing g-C$_3$N$_4$ with carbon nanomaterials (CNM) | Carbon nanomaterial such as carbon nanotubes (CNTs), carbon nanospheres (CNS), graphene oxide (GO) and reduced graphene oxide (RGO) | High thermal, electronic conductivity, remarkable adsorption properties for organic and inorganic compounds | Excess CNM (i.e. RGO) facilitate adsorption of large amounts of the dye molecules onto the catalyst surface thereby reducing light penetration to the photocatalyst |
| Coupling g-C$_3$N$_4$ with semiconductor | Coupling two or more semiconductors to form a semiconductor heterojunction | Improved stability, visible light utilization, charge separation and transfer and more efficient formation of the oxidizing species | Difficult to find a proper semiconductor photocatalyst with suitable band edge position |

Table 1. Surface modification of g-C$_3$N$_4$ technique to improve its photocatalytic performance.
Recent Development of Graphitic Carbon Nitride-Based Photocatalyst for Environmental...  
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Photocatalytic performance efficiency. For example, Wang et al. [19] reported the enhanced photocatalytic performance of g-C$_3$N$_4$/[010] facets BiVO$_4$ photocatalyst fabricated via ultrasonic dispersion method. The aforementioned heterostructure photocatalyst was capable of removing 88.3% of RhB pollutant within 30 minutes under visible light irradiation. Meanwhile, Huo et al. [20] successfully formed the BiVO$_4$/Polydopamine/g-C$_3$N$_4$ heterostructure photocatalyst via facile ultrasonic dispersion and self-assembly at the room temperature. They observed a remarkable photocatalytic degradation of glyphosate under visible light irradiation in comparison to the unmodified photocatalyst.

Furthermore, the photocatalytic activity of pure photocatalyst can be enhanced by the addition of carbon materials as an electron bridge mediator. The addition of carbon nanomaterial provides a structure with a larger specific surface area over which the active component can be well-dispersed, thus increasing the active sites. During the photocatalytic degradation of organic pollutants, carbon materials can be used as an adsorbent to improve the adsorption capacity of semiconductors. Besides, carbon materials can be doped as a photosensitizer for band gap narrowing, which is favorable for expanding the visible light absorption region of semiconductors. The incorporation of electron bridge mediator within the network of the heterostructure system will facilitate the migration of the electron transfer within the photocatalyst, leading to the enhanced charge separation efficiency and photocatalytic activity. In this sense, GO/RGO and CNTs are among the carbon nanomaterial that has been explored to acts as an electron bridge mediator.

3. Recent progress on the development of g-C$_3$N$_4$ photocatalyst for environmental remediation

| Photocatalyst Synthesized Method | Type of pollutants | Pollutants concentration | Source of light | Degradation efficiency | Ref. |
|---------------------------------|--------------------|--------------------------|-----------------|------------------------|-----|
| ZnO/g-C$_3$N$_4$ Impregnation | Phenol             | 5 mg/L                   | Simulated sunlight irradiation | 99.5% of phenol removal achieved after 60 min of irradiation | [42] |
| BiVO$_4$/PDA/g-C$_3$N$_4$ Ultrasonic dispersion and self-assembly | Glyphosate         | 0.1 mM                   | 125 W mercury lamp | 100% degradation after 150 minutes | [20] |
| g-C$_3$N$_4$/BiVO$_4$ NR Methylene blue | 10 mg/L | Visible light | g-C$_3$N$_4$/BiVO$_4$ photocatalyst was about 8 and 7 times higher than that of pure BiVO$_4$ and g-C$_3$N$_4$ | [43] |
| g-C$_3$N$_4$/TiO$_2$/CNT Facile hydrothermal method | MB                 | 6 mg/L                   | 150 W halogen lamp | Ternary hybrid exhibits 5 times higher photocatalytic activity compared to bare g-C$_3$N$_4$ | [44] |
### Table 1: Photocatalysts Synthesized Method Type of pollutants Pollutants concentration Source of light Degradation efficiency Ref.

| Photocatalyst          | Synthesized Method | Type of pollutants | Pollutants concentration | Source of light | Degradation efficiency                        | Ref. |
|------------------------|--------------------|--------------------|---------------------------|-----------------|-----------------------------------------------|------|
| g-C$_3$N$_4$/AC        | NR                 | Phenol             | 50 mg/L                   | 350W Xe lamp    | 100% phenol removal after 160 min             | [45] |
| g-C$_3$N$_4$           | Polycondensation   | Pharmaceutical     | 20 mg/L 10 mg/L           | 35 W Xenon lamp | Photocatalyst showed the capacity to degrade the pollutants in the sequence: tetracycline > ciprofloxacin > salicylic acid > ibuprofen | [46] |
| g-C$_3$N$_4$/CNTs/Au   | Ultra-sonication   | Aqueous Rhodamine (RhB) | 250 mL | Visible light | 100 vol% Au dispersion with a 60: 40 mass ratio of g-C$_3$N$_4$ to CNTs exhibited optimal photocatalytic activity | [47] |

### 4. Conclusions and future directions

The growing concern over the scarcity of clean water sources due to a fast development of industrialization has force a rapid breakthrough dedicated to the development of advanced photocatalyst system. Over the past few years, the studies on g-C$_3$N$_4$ based photocatalyst have witnessed auspicious potential promises by this photocatalyst in environmental remediation applications. To date, the profound photocatalytic performance of g-C$_3$N$_4$ based photocatalyst is mainly governed by its intrinsic features such as metal-free photocatalyst and good light absorption properties owing to its medium band-gap energy of 2.7 eV. In this chapter, the synthesis, properties and photocatalytic application of g-C$_3$N$_4$ are summarized. Then, the most recent strategies for enhancing the photocatalytic performance of the g-C$_3$N$_4$ photocatalyst are highlighted.

Although profound performance had been reported in most of the recent studies, the promising potential of g-C$_3$N$_4$ based photocatalyst has yet to be exploited fully. The main challenges which are yet to be mitigated are (i) green synthesizing method which can produce high surface area and good photostability photocatalyst, (ii) the control of surface kinetics on g-C$_3$N$_4$ photocatalyst which can promote the photocharge separation and migration, (iii) the use of real industrial wastewater in analyzing the performance of g-C$_3$N$_4$ based photocatalyst, (iv) improving the reactor design to achieve the optimum photocatalytic performance with the lowest cost and (v) the utilization of real sunlight as a light source during the analysis process.

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Conflict of interest

The authors declare no conflict of interest.

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