



Synthesis of Carbon Dots and Its Applications in Textiles

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Abstract

Due to its distinctive optical features, cheap cost, eco-friendliness, an abundance of functional groups (such as amino, hydroxyl, and carboxyl), high stability, and electron mobility, carbon dots (CDs), a novel form of carbon-based nanomaterial, have drawn significant scientific attention for years. In this Outlook, we provide a thorough overview of the categorization of CDs based on the analysis of their synthesis, property features, and also their optical characteristics, such as their quantum yield (QY). Additionally, we review several applications of carbon nanomaterial. For example, their roles in being antimicrobial agents, UV blockers/ absorbents, sensors, adsorbents, catalysts as well as fire retardants. Also, their enormous role in treating wastewater resulting from the textile industry has been reviewed.

Keywords: CDs – CQDs – antimicrobial – sensors – wastewater – flame retard – ultraviolet

1. Introduction

When a received stimulus triggers a beneficial, repeatable, and preferably reversible reaction from the textile substrate, this behavior is referred to as "smart" behavior. The smart textile may be able to recognize and react to environmental stimuli or variables that are mechanical, thermal, chemical, electrical, or magnetic. [1-21]

One of the most prevalent atoms on the earth is carbon, which has a huge variety of bonds that it may make with other substances or with itself [22]. Carbon Dots (CDs) are taken into consideration as the brand-new member of carbon primarily-based cloth class, with a tolerable share of hydrogen, oxygen, and often sp^2 hybridized carbon atoms in nature [23]. They have a length of as much as less than 20 nm. And because of their unique optical properties, low cost, eco-friendliness, abundance of functional groups (such as amino, hydroxyl, and carboxyl), high stability, and electron mobility, Carbon Dots (CDs), a new category of Carbon-based nanomaterial, have attracted significant research interest for years [24].

According to their various formation mechanisms, micro-/nanostructures, and features, CDs are currently primarily categorized as Graphene Quantum Dots (GQDs), Carbon Quantum Dots (CQDs), and Carbonized Polymer Dots (CPDs). The graphene layer and carbonization level can be changed to create associations between them (**Scheme 1**) [23].

The application of CDs is defined by the way they are synthesized and where they come from, whether they are prepared in a lab or extracted from a bio source. They can be used as UV protectors, sensors, and fire retardants and have antimicrobial activity, and fluorescent and biocompatibility properties. [25-28]

And regarding their excellent fluorescent and biocompatibility behavior, Mulberry leaf carbon dots (CDs) are reported to exhibit strong near-infrared fluorescence with an absolute quantum yield of 73% and a full width at a high maximum of 20 nm, Silkworms that eat such CDs emit bright red fluorescence, grow healthily, form cocoons normally, and finally metamorphose into moths. The cocoons are pink in sunlight and fluoresce bright red under UV light [29].

As CDs are considered non-toxic materials, they can be synthesized from green sources such as fruits and leaves, each fruit presents a different application for CDs. For example, using canon ball fruit to get CDs, and then they are used as sensitive detectors of toxic metal ions such as Fe^{3+} [30], also CDs can be synthesized from *Phyllanthus emblica* and be used in the detoxification of textile effluents [31]. We can see the huge green impact of CDs which is a game changer in the textile field due to their toxic influence on the environment, but CDs are now here to change that.

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Receive Date: 12 February 2023, Revise Date: 06 March 2023, Accept Date: 14 March 2023, First Publish Date: 14 March 2023

DOI: 10.21608/ejchem.2023.192739.7595

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In this study, we explain the different syntheses of CDs and the various application of this mentioned material in the textile industry.

2. Synthesis of CDs

The synthesis of CDs highly depends on their application on fabric; therefore, the synthesis of CDs differs between natural and Synthetic methods.

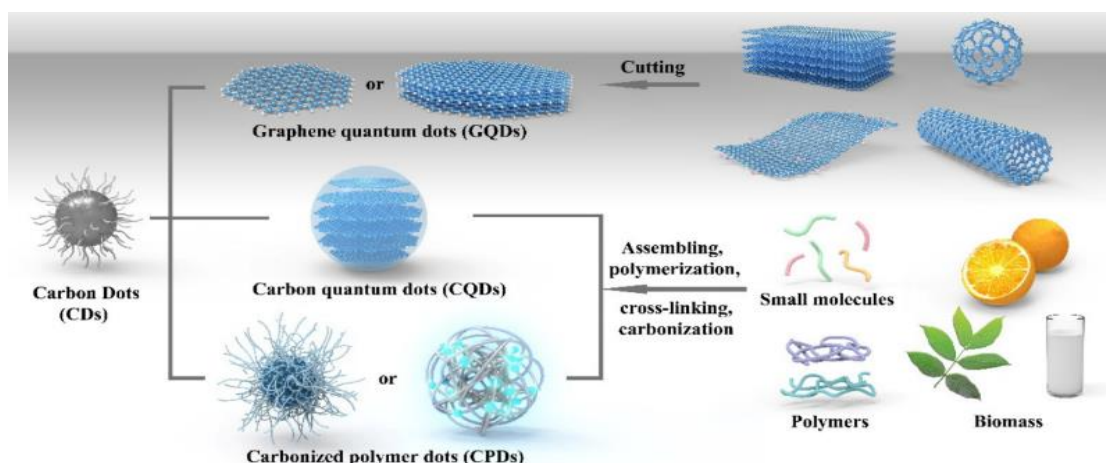
2.1. Green Synthesis of CDs

2.1.1. Green synthesis of fluorescent CDs from canon ball fruit

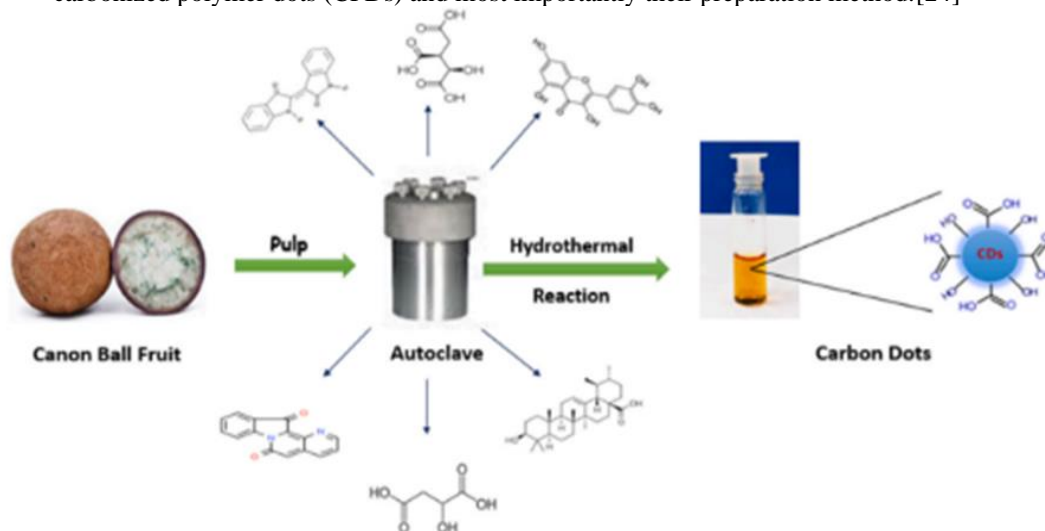
G. Ashok Varman et al. have explained and studied the preparation of CDs as shown in (Scheme 2). The pulp of the Canon Ball fruit (CB) was crushed. The juice was then filtered to remove large pulp. 20mL of the juice is removed and treated with 30 mL of distilled water placed in a Teflon-Lined stainless-steel autoclave heated at 200°C for 5 hours. After being allowed for cooling naturally to room temperature, the obtained brown-yellow solution was centrifuged and filtered using membrane filter paper, the filtered solution was then stored for further studies [30]

The Quantum yield and the size of the synthetic CDs were examined by using TEM analysis and it was found that they have a uniform sphere-shaped quality and is less than 15 nm in size, and as for the quantum yield, it was measured by utilizing Quinine Sulfate as standard reference (QY 54%). The QY is determined to be (7.24%) [30].

Also, by the FT-IR spectra of the synthesized CDs, it is abundantly obvious that they are rich with oxygen groups present on their surfaces, giving them the maximum solubility and dispensability in aqueous media. Also, A significant emission peak with a maximum intensity at 380 nm is seen in CDs, according to observations, because CDs have excitation-dependent emission properties. In addition, when CDs were stored at room temp. for 30 days while recording their fluorescence spectra every five days to measure their stability, it was determined that they are extremely stable for long amounts of time with also no suspensions during storage time [30]



Scheme 1: Classification of CDs: including graphene quantum dots (GQDs), carbon quantum dots (CQDs), and carbonized polymer dots (CPDs) and most importantly their preparation method. [24]



Scheme 2: Schematic representation of the preparation of carbon dots from CB fruit by HT method [30]

2.1.2. Green synthesis of CDs from tangerines

Zahra Fathi, et al have explained the green methodology of preparing CDs from tangerines as follows:

Carefully cleaned tangerines were dried using tissue paper. After that, tangerine juice was made by pressing the cleaned fruits. A 100 mL Teflon-lined autoclave containing 60 mL of tangerine juice was put into an oven set to 180 °C for 7 hours. After that, the hydrothermal autoclave reactor was allowed to gradually cool down at ambient temperature. Then, the resulting brown solution was centrifuged at 10,000 rpm for 15 mins to remove big particles from the solution. The supernatant was then filtered using a 0.22 m filter membrane to increase purification [32].

The analysis of the produced CDs has then shown that by using a comparable approach and using a solution with a known fluorescence QY as a reference, the quantum yield of CDs (QY CDs) was estimated. As a fluorescent reference in this study, quinine sulfate was chosen because of its 0.54 fluorescent quantum yield. Accordingly, when stimulated at 365 nm, CDs' fluorescence QY was estimated to be roughly 23%. This high quantum yield value was obtained by surface passivating CDs with nitrogen (N), which has a significant impact on CDs' optical properties. And when exposed to UV light, CDs display brilliant blue fluorescence. According to the UV-visible spectra, CDs feature a sizable absorbent band at 280 nm. Additionally, the photoluminescence emission spectra exhibit a notable dependence on the excitation wavelength and move to a longer region as the excitation wavelength rises. As for the morphology of CDs, Produced CDs have a height of around 4 nm, which adds up to 3-5 graphite layers. Additionally, it is stated that CDs measure 6.9 nm. These findings indicate that produced CDs are monodisperse, hydrophilic, extremely tiny, negatively charged nanoparticles. The fact that hydroxyl groups and carboxylate existence act as functional groups on the surface of the CDs also contributes to the negative charge. The stability of CDs in aqueous solutions and hydrophilicity both improve with the number of hydroxyl groups [32].

2.1.3. Synthesis of CDs from mulberry leaves

Fatemeh Salimi et al. hydrothermally synthesized CDs. A combination of 30 grams of fully cleaned white mulberry and 70 mL of deionized water was agitated in an oil bath at 60±1 °C for one hour. The resulting aqueous extract was carefully filtered using Whatman No. 1 filter paper. Finally, the material was placed into a stainless-steel chamber and kept at 160 ±1 °C for 6 hours after being centrifuged (7155 × g for 15 min.) The resulting solution was passed through a sterile polytetrafluoroethylene syringe filter (0.42 m) and centrifuged at 16 099 × g for 30 min. The CDs were then

dried and stored at 4 °C in a sterile environment after being produced [33].

According to Sun et al., the majority of CDs radiate a blue to yellow and dark brown color with the strongest luminosity. In this regard, a solution that glows intensely green under the UV lamp and is dark brown in natural light indicates that CDs were successfully produced [34].

The optical absorption peak of CDs, which has a maximum absorption of about 250–275 nm with a tail extending into the visible range, is their signature characteristic of CDs. And the morphology of the synthesized CDs can be specified as the average size of C-dots was 4.1 nm, and 95% of them were less than 10 nm [33]

2.1.4. Synthesis of CDs from postconsumer silk waste

R. Vadivel et al. prepared CDs from silk cloth waste and the procedure went like this: The used silk fabric was cut into little pieces, and 0.5 g of it was placed in a stainless-steel autoclave that had been lined with Teflon. Next, 20 mL of 20% phosphoric acid was added as an oxidizing and passivating agent. A yellow-colored solution was produced when the autoclave was sealed and held at 250°C for 5 hours, indicating the production of CDs. And to get rid of the remains of unreacted silk fabric, the mixture was diluted. The resultant yellow-tinted solution's pH was determined to be more acidic, which suggests that there is too much phosphoric acid present. The yellow solution was dried and redissolved in ethanol, then dil. was added drop-by-drop while stirring, to remove the excess phosphoric acid. Using Whatman 40-grade filter paper, the final product was filtered. After that, to get rid of bigger particles, it was centrifuged for 20 minutes at 15,000 rpm. The resulting crystal-clear solution was vacuum dried, then redissolved in deionized water, and applied to additional research [35].

A TEM picture of the CDs made from waste silk shows the spherical shape of the as-prepared CDs. By examining 25 particles, the statistical diameter of the CDs was calculated from the TEM picture to be 6.1±2.2 nm. The spectrum of UV-visible absorption shows a band at 275 nm and a hump at 362 nm. Two excitation peaks at around 260 nm and 365 nm, which refer to core and surface excitations, are visible in the excitation spectra of CDs (emission measured at 446 nm).

When compared to the quantum yields of the majority of the reported CDs made from biowaste, which are typically less than 10%, the fluorescence quantum yield of the CDs is estimated to be around 19.1% which is remarkable. These CDs' high value extends their use in consumerist industries. The CDs have high photostability and storage stability (in ambient lighting). Their extensive surface functionalization may be the cause of the solution's high stability [35].

2.1.5. Synthesis of Nitrogen-doped CDs from *Phyllanthus emblica* (amla) fruits

Velusamy Arul et al. have prepared Nitrogen-doped CDs (N-CDs) from amla fruits and the procedure was as follows: *P. emblica* fruit weighing around 50g was carefully chopped into small pieces, properly rinsed in running water, and mechanically crushed. The produced amla extract was filtered twice: once using a Whatmann 40 filter paper and once using cotton. As a biogenic source, the resulting *P. emblica* fruit extract was used to create N-CDs [31].

The creation of N-CDs from *P. emblica* extract involved a straightforward, one-pot hydrothermal carbonization procedure. In this procedure, a stainless-steel autoclave with a 50 mL Teflon lin was used to combine 29 mL of *P. emblica* extract with 1 mL of aq NH_3 . For 12 hours at 180 °C and the autoclave was held in a hot air oven. The reaction was finished, and the autoclave was then allowed to cool at 25 °C. The extract was centrifuged for one hour at 10,000 rpm after being filtered through a Whatmann 40 filter paper and allowed to come to room temperature. The resulting N-CD-containing dark brown solution was carefully collected and kept at 4 °C in a refrigerator for further studies [31].

At 217 and 317 nm, the UV-visible spectrum displayed maximum absorption. And at 365 nm, the N-doped CDs radiate a bright blue hue. A fluorescence approach was used to calculate the quantum yield, which resulted in values of 0.34 for undoped CDs and 0.41 for doped CDs. Regarding the shape of N-CDs, the HR-TEM picture shows that the CDs are 4.08 nm in diameter [31].

2.1.6. Green synthesis of CDs extracted from *Aloe-vera*

Pooja Devi et al. have used aloe vera as a source for CDs. Aloe Vera, which was employed as a forerunner to carbon, was gathered from the garden, rinsed with water, and kept in the refrigerator (4°C) until needed. Aloe Vera obtained in this manner was heated to a high temperature in a hot air oven to acquire the extract. After filtering, the extract was heated once more to a high temperature to cause carbonization. The resultant dark-colored substance was diluted with water before being purified in a dialysis membrane against water by observing CDs' optical properties using photoluminescence (PL) and UV-Vis-spectroscopy, the influence of synthesis temperature (160–250 °C) and time (10–30 min) on CDs nucleation in the extract was thoroughly investigated. Aloe Vera-derived CDs display typical UV-vis absorption spectra at around 340 nm, and under ideal synthesis conditions, produced CDs of size between 6 and 8 nm have a respectably high QY of 12.3% [36].

2.2. Manufactured synthesis of CDs

2.2.1. Synthesis of Terylene Carbon Dots (TCDs)

Tianwu Hu et al. have reported that CDs can be synthesized from terylene by Utilizing terylene-dyed azo dye Red 167 and urea as raw ingredients, the terylene CDs (TCDs) were made using a one-step hydrothermal process. In specifics, 10 mL of an ethylene glycol solution was used to disperse 0.5 g of terylene colored with red 167. The dispersion was further stirred for a further 15 minutes before receiving 0.5 g of urea. The mixture was put into a 25 mL Teflon-lined container, heated for 12 hours at 200°C, and then allowed to cool naturally to ambient temperature. Centrifugation at 12,000 revolutions per minute and a 0.22 μm microporous filter were used to purify the solution. The solution was then dried at 80°C in a vacuum oven to produce the solid TCDs, which were then re-dispersed into deionized water. The water-soluble TCDs were then kept in storage at 4 °C for future usage [37].

The TCDs were almost spherical particles with high dispersibility. The particle diameter is 4.7 ± 0.1 nm on average. The optical characteristics of TCDs were also examined using UV-vis and FL spectra. There were two UV-vis absorption peaks, one at 238 nm and the other at 300 nm. As was noticeable from the fluorescence spectra, the optimum excitation peak for TCDs was at 368 nm, whereas the greatest FL emission peak was at 490 nm. Additionally, TCDs showed a green FL in 365 nm UV light, which was consistent with FL spectra. Further, the TCDs' fluorescence stability was investigated. The fact that the fluorescence intensity alters slightly as the TCDs age shows that they have high stability [37].

2.2.2. Synthesis of Carbon Quantum Dots (CQDs)

Umairah Abd Rani et al. have studied the creation of CQDs in different ways as they are divided into several methods:

- a) Multi-walled carbon nanotubes were subjected to two hours of sonication in a solution of strong nitric and sulfuric acids, followed by eight hours of refluxing at 80 °C. After the reaction, the acidic medium was diluted with sodium hydroxide before being dialyzed with a dialysis membrane to eliminate the extra acidic solutions, the concentrated acids were used to reduce the precursor materials' size and functionalize them [38].

Based on various heat settings, this method can also provide CQDs with a potent photoluminescent effect. Due to the carbonization and oxidation events, this technique also encourages a significant quantity of oxygenated functional groups (hydroxyl, carboxyl, and carbonyl) on the CQD structures. And as for significant quantum confinement and edge effects, the emergence of these functional groups will make CQDs more

soluble in aqueous media while also exhibiting exceptional conductivity properties. This approach might be regarded as a straightforward reaction. However, because concentrated acid is used, the further purification step takes a long time [38].

- b) In a different study, citric acid was heated to 180 °C for three hours in the air in a glass container to create CQDs passivated with carboxyl groups through the pyrolysis process. Citric acid underwent high-temperature thermochemical decomposition during this procedure, producing CQDs with a high energy density that was made of oxygenated organic molecules [38].
- c) The ultrasonic procedure is another technique that has been utilized to create CQDs. This procedure involves dissolving glucose in water first, then adding sodium hydroxide solution. In several experimental studies, the glucose was oxidized using concentrated sulfuric acid or hydrogen peroxide. For four to five hours, ultrasonic waves were applied to the mixed solution. Based on that technique, high energy that can disrupt carbon bonds, as well as chemical and physical transformations, was produced by agitating the solution's particles with ultrasonic energy. This process can also increase the number of free radicals and bubbles produced, increase the reaction's reactivity, control the morphology, and possibly even lessen the surface flaws of CQDs [38].

Hossam E. Emam et al. have as well studied the synthesis of CQDs and the procedure is as follows:

Synthesis of 4-(2,4-dichlorophenyl)-6-oxo-2-thioxohexahydropyrimidine-5-carbonitrile (target molecule [TM]):

Sodium ethoxide (25 mL) was made by dissolving 1 g of sodium metal in 25 mL of anhydrous ethyl alcohol. The mixture of 2,4-dichloro benzaldehyde, thiourea, and ethyl cyanoacetate was agitated at room temperature for 60 mins. After adding HCl to neutralize it, the reaction liquid was put into an ice bath. Ethyl acetate: n-hexane (2:98) was used to purify the precipitated solid using column chromatography, yielding a reddish-yellow crystal with a 93% yield percentage and a melting point of 149 °C–151 °C [39].

Synthesis of carbon quantum dots

A hydrothermal method was used to cluster CQDs from the synthesized TM. This technique involved dissolving 2 g of TM in 100 mL of DMF, moving the liquid to a vertical hydrothermal autoclave reactor, and then heating the reactor to 210 °C for 6 hours. To extract highly purified/monodispersed/pure CQDs for additional analysis, the dark-brown reaction liquid was allowed to cool to room temperature and dialyzed with DMF (Dimethylformamide) using puralyzer dialysis kits. For over 24 hours to provide very pure,

monodispersed, and pure CQDs for additional analysis [39].

2.2.3. Graphene Quantum Dots (GQDs)

Enamul Haque et al. have explained that GQDs can be synthesized via an ultrasound method as follows: In liquid, ultrasound may create alternating low- and high-pressure waves that can cause tiny vacuum bubbles to grow and burst. These gas bubbles result in deagglomeration, powerful hydrodynamic shear forces, and high-speed impinging liquid discharges. All these characteristics work together to provide ultrasonography the capacity to break apart Graphene sheets (GSs) into GQDs. The GSs are typically first oxidized in concentrated sulfuric acid or nitric acid in a typical method. To create GQDs, the mixture is then sonicated for 12 hours. With the help of this method, monodisperse GQDs with diameters between 3 and 5 nm have been created [40].

GQDs and CDs both share the same photoluminescence (PL) characteristics. Although all known GQDs, regardless of how they were created, are photoluminescent, it is still unclear where their emission characteristic originated. Different processes can create GQDs that emit in the deep UV range in blue, green, yellow, red, or white, with QY ranging from 2% to 22.4% [40].

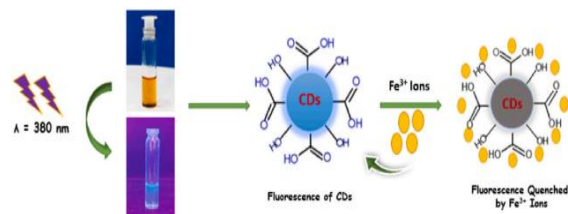
3. Applications of CDs

3.1. CDs as sensors, adsorbents, and catalysts.

3.1.1. CDs as sensors and catalysts for Fe^{+3}

The presence of hazardous metals, with both heavy metal ions and nuclear metals, is one of the severe ecological concerns. Wastewater may include single or combined forms of hazardous metals. Their risk is increased by the disposal procedure's complexity. One of the metals is Fe^{+3} [41]. In addition to the difficulty of detecting these metals.

For the detection of Fe^{+3} ions, CDs as fluorometric sensors with a range of limit of detection (LOD) values obtained from various precursors have been reported in numerous research studies.



Scheme 3: Schematic representation involves the quenching mechanism of CDs by Fe^{3+} Ions [30].

For example, G. Ashok Varman et al. utilized CDs that were extracted from Canon Ball fruit and used them as detectors for metal ions and it was confirmed that these specific CDs have high sensitivity for Fe^{3+} ions. As the CD solution was supplemented with various

concentrations of Fe^{3+} solutions, measurements of the fluorescence response and absorbance were made. The fluorescence response of CDs at various Fe^{3+} ion concentrations. Due to its high sensitivity to Fe^{3+} ions, it exhibits a reduction in emission intensity with increasing Fe^{3+} concentration [30].

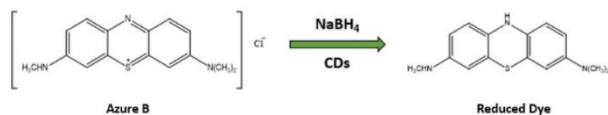
It was demonstrated that fluorescence quenching was brought on by static when Fe^{3+} ions were added (**scheme 3**) quenching process that includes complicated creation between the acceptor chromophore and the donor fluorophore by omitting interactions between excited states and the ground state. Here, CDs serve as the acceptor chromophore, and the fluorophore as the donor is the ion Fe^{3+} . The presence of oxygen could be the cause of the complexation. Hydroxyl and carboxylic groups are rich surface moieties that readily can communicate with the ions of Fe^{3+} [30].

As catalysts

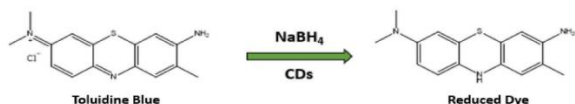
The carbon dots have several benefits, including minimal cost, a strong degree of crystallinity, biocompatibility, and simplicity of conducting chemical processes to alter the nature of their surface. Due to these positive characteristics, carbon dots have a tremendous potential to replace the conventional catalysts currently employed in the treatment of water from organic dyes [42].

Through the catalytic reduction of two textile dyes, (Azure B) AB (**scheme 4**) and (Toluidine Blue) TB (**Scheme 5**), with the aid of NaBH_4 , the catalytic activity of CDs was examined [30].

It has been found that when only a small quantity of CDs is applied together with NaBH_4 , the dye is decreased to its maximum in less than 6 minutes. This demonstrates that synthetic CDs operate as a catalyst for the reaction that makes it possible for electrons and hydrogen to be transferred to the dye molecules. And adsorption of the dye molecules and BH_4^- ions from the reducing agent onto the surface of the CDs results in an electron transfer that reduces the dye molecules [30]



Scheme 4: The reduction reaction of the AB Dye [30].



Scheme 5: The reduction reaction of TB dye [30]

It has been determined that manufactured CDs function as an electron transfer medium that lowers the energy barrier between reactant and product by quickening the process [30].

3.1.2. CDs as sensors and adsorbents for Cr (VI) Sensitivity and selectivity of Cr (VI)

As part of the heavy metal series, hexavalent chromium Cr (VI) is produced or disposed of in industrial wastewater, including textiles. The predominant form of Cr (VI) is HCrO_4^- in addition to carcinogenic and mutagenic ions such as CrO_4^{2-} and $\text{Cr}_2\text{O}_7^{2-}$ ions. Experiencing a Cellular respiratory disorder are likely to develop at a particular level of Cr (VI), cancer, genetic abnormalities, and even fatality. Consequently, it is essential to find and get rid of Cr (VI) in industrial wastewater [37].

To effectively detect and adsorb Cr (VI), Tianwu Hu and his co-researchers created chitosan non-woven fabric enhanced with fluorescent CDs from terylene. On a wet-spun chitosan non-woven fabric, the CDs were modified by condensation of amino and carboxyl groups. This CNF-TCDs3, a functionalized fabric, displayed remarkable selectivity and sensitivity to detect Cr (VI) [37].

CNF-TCDs3 were exposed to Cr (VI) to determine the presence of the compound, and as the ion concentration increased, the intensity of the fluorescence gradually dropped until it was entirely quenched. Additionally, while comparing TCDs with CNF-TCDs3 for the detection of Cr (VI), we found that the latter had a lower LOD and greater sensitivity to Cr. In the meantime, the coexistence of ions was also taken into account, and the outcome was consistent. This demonstrated that, in contrast to other ions, Cr (VI) had a clear quenching effect on the fluorescence of CNF-TCDs3 [37].

Adsorption of Cr (VI)

The researchers discovered that Cr (VI) was partly reduced to Cr (III) during the adsorption process. and the CNF-TCDs3 also adsorb the reduced Cr (III) ions. CNF-TCDs3 adsorbs a tiny quantity of Cr (III) to boost the adsorption capacity of Cr (VI), which absorbed the same concentration of Cr (III) and Cr (VI) sequentially. This could be because Cr (III)'s positive charge assisted CNF-TCDs3 in adsorbing dichromate ions. Cr (VI) was adsorbed by electrostatic attraction, and the adsorption process was verified to be the protonated positively charged amino groups. The coordination of hydroxyl groups may be the cause of the adsorption of Cr (III) [37]

Adsorption and desorption cycle

After five cycles of testing, the maximum adsorption capacity of CNF-TCDs3 remained almost constant, showing that the material had high reusability. In addition, it possessed a very high desorption capacity, with a five-desorption average desorption rate of over 90%. Additionally, the desorption rate was examined, and it was shown that the desorption balance could be achieved in less than 1 minute, demonstrating that the NaOH could effectively and quickly desorb Cr (VI).

As soon as Cr (VI) was adsorbed on CNF-TCDS3, it was obvious because the material's color changed from white to yellow. The color of CNF-TCDS3 became white when 0.1 M NaOH was used as a desorbent. The color of CNF-TCDS3 darkened after five cycles of repeated studies, presumably due to the remaining Cr (VI) from previous cycles. Adsorption and desorption might have an impact on fluorescence brightness. The fluorescence brightness dims after multiple repeats, which is caused by the partial desorption of Cr (VI) [37].

3.1.3. Nitrogen-CDs as sensors for acetone

Chronic breath can be used as a sign of health issues associated with diabetes. A person with diabetic ketoacidosis may have a strong acetone-like breath scent, a sign of elevated blood ketones. Therefore, it has been important to build a practical fluorescent textile mask to identify acetone vapor in diabetes patients' breath. And here is the role of CDs.

A.T. Mogharbel, R.A. Pashameah, A.A. Alluhaybi, et al. prepared and immobilized bright nitrogen-doped carbon dots (NCDs) onto a cotton mask for acetone detection, a quick and clean method for processing rice straw was developed. NCDs were made using one-pot hydrothermal carbonization of cellulose diacetate with NH_4OH as a passivating agent. NCDs demonstrated a quantum yield (QY) of up to 24.03% with emission wavelengths of 439 nm and excitation wavelengths of 381 nm. The cotton cloth was impregnated with a thin layer of luminous cellulose carbon dots using this technique. The inner filter effect on NCDs' fluorescence was able to be quenched by acetone gas, displaying high sensitivity and selectivity [43].

Emission spectra were used to examine the quenching effect of the NCDs-cotton test in various acetone solutions. According to the study, acetone selectively quenched the fluorescence of the NCDs-cotton test. The efficiency of fluorescence quenching and acetone concentration was found to be significantly proportional. (10-200 ppb), indicating a 10-ppb defined level. Also, the comfort qualities did not alter much when the CD ratio increased [43].

3.2. CDs as flame retardants

3.2.1. CDs-Ammonium Polyphosphate

A type of biomass carbon dots (CDs) particles was included in the ammonium polyphosphate (APP) layer to create a novel effective CDs-based APP (CDs-APP) composite flame retardant using the integration technique to enhance the flame-retardant performance of the cotton fabric. The cotton cloth surface was then covered with the CDs-APP layer.

Baoxia Xue et al. stated that the preparation of CDs-APP Flame Retardant is executed as follows: The CDs were created from citric acid using a single hydrothermal phase. A beaker was filled with 1 g of APP powder, 0.1 mL of KH-550, and 100 mL of

anhydrous ethyl alcohol. With magnetic stirring, the mentioned solution was heated to 70°C for one hour. After adding 0.5 g of CDs, the aforementioned solution underwent a 30-minute ultrasonic dispersion. The solution was then heated for a further 2 hours at 50°C at a steady pace. After lyophilization and dialysis, CDs-APP powder was produced [44].

To combine CDs-APP powder with self-crosslinking silicon-acrylic emulsion and distilled water, ultrasonic dispersion was used for a certain length of time. Additionally, 30% of the mass fraction was made up of FR powder. The cotton cloth was then equally coated on both sides using a coating film [44].

The CDs-APP coated cotton fabric's flame-retardant process is that The APP in the CDs-APP coating film would thermally breakdown under the influence of the flame to produce a forceful dehydrating agent of polyphosphoric acid, which catalyzes the dehydration and carbonization of the cotton fabric's surface to make carbides. These carbides can create a fluffy carbon layer with a network-like structure when exposed to CDs. This layer of solid, compact carbon can act as a flame retardant and smoke suppressant by slowing the spread of flammable gases and smoke and preventing heat from being transmitted through it. The surface of the CDs-APP coated cotton fabric was equally coated with polyphosphoric acid created by the breakdown of APP and non-combustible gases such as CO_2 and H_2O created by heating. These substances serve as an oxygen barrier and stop the cloth from further burning. A high-quality flame-retardant system of CDs-APP synergistic carbonization is made up of CDs that improve the carbon layer and APPs that catalyze carbonization. The combustion reaction was slowed down by the physical barrier effect and catalytic char generation, which also increased the cotton fabric's thermal stability and flame-retardant effectiveness [44].

3.2.2. Gelatin-CDs-Polyethylene Terephthalate

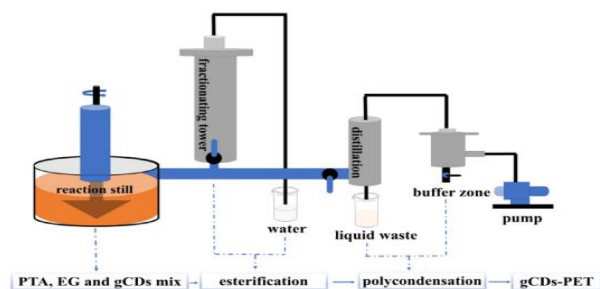
Carbon Dots (CDs) were originally used as co-polymerizable flame retardants for polyethylene terephthalate (PET) due to their superior flame-retardant efficiency, environmental friendliness, and richness of surface functional groups [45].

W. Gu et al. synthesized Gelatin CDs (gCDs) by one-step hydrothermal method from polytetrafluoroethylene and created a flame-retardant co-polyester by copolymerizing it with pure terephthalic acid (PTA) and ethylene glycol (EG) [45].

Before usage, PTA powdered raw materials were first dried for 12 hours at 120 °C in a vacuum drying oven. Following that, PTA, EG, and gCDs were combined in the polymerization reactor and equally distributed by an impeller for 5 minutes before using. The mixture was then esterified for two hours at 240 °C. The polymerization reactor was then supplemented with TPI, HyMax 1010 -anti hydrolysis stabilizer-, and a little quantity of EG to continue the esterification

process for 30 minutes at atmospheric pressure. The amount of water created in the meantime can be used to determine if esterification is complete[45].

In this experience, roughly 151 ml of water may be obtained based on the mole ratio of the raw ingredients. Bis(2-hydroxyethyl) terephthalate was the item stated above (BHET). Finally, a polycondensation process took place in a high vacuum, resulting in the production of gCDs-PET at 280 °C. The full gCDs-PET setup procedure was described in detail in (Scheme 6)



Scheme 6: Diagram of the process for making gCDs-PET[45]

Because gCDs have been grafted into PET chains and helped create an internal crosslinking, which ensures that heat is evenly transmitted throughout the PET matrix when the gCDs-PET composites are ignited, TTI is delayed. Second, the macromolecular chain starts to break as the intensity of the combustion increases, and gCDs catalyze degradation [45].

According to testing, the peak rate of heat release significantly decreases from 1144 kW/m² to 656 kW/m², and the production of smoke and harmful gases such as CO and CO₂ is also noticeably reduced. Additionally, the mechanical strength of 2.0-gCDs-PET is somewhat improved. The tensile strength of PET improves from 50.46 MPa to 54.96 MPa, while the elongation at break decreases from 300% to 545%. Then the flame-retardant mechanism gCDs catalyzes the thermal decomposition of PET to generate a shielding carbon layer is revealed. This layer hinders the escape of combustible components to the exterior and expands the formed char, which stops the combustion reaction. To achieve the goal of being flame retardant, non-combustible gases are produced to decrease the oxygen concentration. Finally, fibers with outstanding mechanical properties could be created using 1.0 gCDs-PET [45].

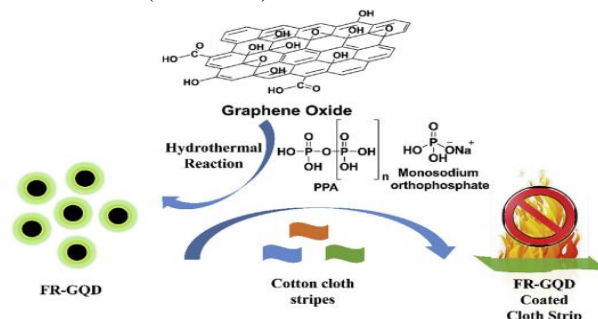
3.2.3. Graphene Quantum Dots

Although boron-containing compounds and halogenated flame retardants were widely utilized, they produce pollutants that can be hazardous to people and the environment and can't be used on clothing [46].

Materials containing phosphorus have been investigated and utilized extensively as beneficial, cost-effective flame retardants. It is well known that Flame retardants (FRs) that include phosphorus produce ash

waste, which acts as a barrier to put out fires. They also endure numerous washing cycles, which is an added benefit because it means they continue to be more effective than other FRs. The most stable and practically useful allotrope of carbon, graphene, can be employed to improve the fire-retardant efficacy of phosphorous-containing compounds.

The finest two-dimensional carbon-containing nanoparticle, graphene, has distinct structural, chemical, and thermal characteristics[47]. And GQD possesses several intriguing advantages, including minimal cytotoxicity, great water solubility, strong biocompatibility, and large surface area. When phosphorous functional groups are added to the surface of GQD, its qualities make it a useful material for the creation of transparent flame retardants. The translucent FR-GQD solution aids in maintaining the fabric's natural color (Scheme 7).



Scheme 7: Synthesis of the graphene-supported highly potent transparent flame retardant[48]

R.V. Khose et al. used water to dissolve graphene oxide, and then PPA and NaH₂PO₄ were added. 30 minutes of ultrasonication of the mentioned combination were followed by transfer to an autoclave made of stainless steel. 18 hours were spent keeping an autoclave at 150 C in the vacuum oven. The solution was then filtered off, and the filtrate was spun at 8000 rpm for 10 minutes. After that, it underwent rotary evaporation to produce FR-GQD [48]. The synthesized GCDs have phosphorous-aided functional groups on them.

In the flame-retardant experiment, the FR-GQD coated fabric exhibits great durability as formulated. The texture and color of the cotton material are neither altered nor changed when the as-prepared FR-GQD is applied to it. The FR-GQD coated fabric initially produced a little amount of smoke and went black throughout the experiment, but it didn't catch fire for more than 300 seconds (5 minutes) and retained its original shape with only a tiny lean. As it was discovered that FR-GQD-coated fabric preserves the fiber and structure by producing a char residue layer on the cloth surface that shields the fiber underneath. Unlike typical cotton, which burned down entirely in 15 seconds by forming a thin black pile. Excellent flame-retardant qualities of FR-GQD coated fabric have been demonstrated; these qualities will be useful in daily life. The first transparent

graphene-supported nanomaterial (, FR-GQD, might be seen as a general strategy for eco-friendly mass manufacture for a variety of useful uses, including flame retardation [48]

3.3. CDs as antimicrobial agents

3.3.1. (Cotton/Ag/GQDs) nanocomposite

Numerous additional Gram-positive and Gram-negative bacteria, including *E. coli*, have developed alarming levels of resistance. These germs can cause disorders including dysentery and diarrhea. Because of this, antibacterial materials have attracted significant interest in preventing the spread of harmful microorganisms and maintaining human health. Therefore, advances in new antibacterial surfaces that could slow or stop the growth of bacterial biofilms on all possible surfaces must get special attention in addition to the development of new classes of antibiotics.

H. Teymourinia et al. have directly produced Ag nanoparticles (NPs) on the cotton pad, they employed green synthesized graphene quantum dots (GQDs) as both reduction and immobilizing agents. Since Ag⁺ ions are first absorbed by the COH group on cotton fibers and then reduced to Ag NPs by GQDs, straight manufacture of Ag NPs on cotton results in enhanced immobilization of Ag NPs. In addition, GQDs link Ag NPs to cotton's surface. GQDs may connect Ag NPs and cotton surfaces through a range of functional groups including CO, COOH, etc. GQDs themselves exhibit an antibacterial impact, collaborative benefits, and boost Ag NPs' antibacterial activity, which is another benefit that was attained.[49]

3.3.2. Nitrogen-doped carbon quantum dots Polyethersulfone membrane

Compared to traditional techniques, membrane filtration has received a lot of attention since it is inexpensive, simple to use, uses very little chemical energy, and has a high level of efficacy. But because of the bacterial growth on the moistened surface of membranes which restricts the use of membranes, it became a must to establish membranes with antimicrobial activities to deal with this issue.

Recently, the use of CDs in membrane technology has drawn a lot of interest. Numerous characteristics make CDs a rising option for membrane modification. H. Koulivand, et al. studied N-doped carbon dots, which are excellent for a broad range of uses due to their increased stability, biocompatibility, and density of functional groups on the surface, and they were demonstrated to exhibit substantial antibacterial activity against both Gram-positive *S. aureus* and Gram-negative *E. coli*. It is conceivable to believe that N-CQDs' antibacterial activity is a result of a chemical process. And by using the phase inversion technique, nitrogen-doped carbon dots were added to the

polyethersulfone (PES) membrane polymer to create antibacterial membranes. [50].

N.A. Travlou et al hydrothermally obtained N-CQDs and stated that the primary determinants of the dots' complicated antibacterial activity were their sizes and particular surface chemistry. The protonated forms of the nitrogen functional groups (amides/amines) and the negatively charged cell membrane interacted electrostatically to kill the bacterial cells, most likely leading to the production of active oxygen species (O₂⁻, HO₂⁻, OH⁻) that the water facilitates generating [51]. Compared to plain PES, all of the NCD-blended membranes performed better. as highly promising antibacterial and hydrophilic nanofillers.

3.3.3. Carbon quantum dot-filled cotton clothing for military

Hossam E. Emam et al. stated that the production of military textiles is planned to use a new approach. To create carbon quantum dots (CQDs), a brand-new fluorescent aromatic chemical called 4-(2,4-dichlorophenyl)- 6-oxo-2-thioxohexahydropyrimidine-5-carbonitrile (Target molecule [TM]) is created. Sequentially, TM and CQDs were used to create resistant cotton textiles that were fluorescent, and antibacterial. The prepared TM and CQDs were loaded onto the native and cationized cotton fabrics by dipping methods. The cotton and cationized cotton textiles were adjusted using the manufactured TM and CQDs. The functional or aesthetic groups (OH, NH, NH₂, O, N, and S) of the produced TM -CQDs might form hydrogen bonds with the hydroxyl groups of the cotton fibers' cellulose chains to interact chemically with the cotton textiles [39].

Because CQDs can readily infiltrate the microbial cell walls, control and arrange their sizes and shapes, as well as their ornamental functional groups which generate Reactive Species (RS) such as (singlet oxygen, singlet sulfur, singlet nitrogen, and hydroxyl free radicals), they have great microbicide efficacy against *E. coli*, *S. aureus*, and *C. albicans*. Eventually, cell death results from these previous CQDs' characteristics. The treated cotton fabrics showed greater durability and preferable antimicrobial activities unlike the untreated fabrics [39].

3.4. CDs as UV absorbents/blockers

3.4.1. Boron and Nitrogen co-doped carbon dots as UV absorbents

The right amount of sunshine exposure is good for human health, but too much UV radiation may damage the skin, speed up the aging process, and even lead to skin cancer. Thus, a method for creating textiles with UV protection is studied. Many CDs can be utilized as UV-absorbing finishing agents for cotton textiles because of their great UV absorption capabilities [52].

S. Cheng et al. used boron and nitrogen-doped carbon dots (BN-CDs) to increase the UV absorbance of cotton textiles. They made them utilizing a one-step

hydrothermal synthesis process, with citric acid, ammonium citrate, and glucose serving as various carbon sources, ethylenediamine serving as a source of nitrogen, and borax serving as a supply of boron. Additionally, every one of the ready BN-CDs had a nearly spherical shape with diameters between 5-8 nm. The cotton fabric was sprayed with the combined aqueous solution of (BN-CDs), and then it was rolled and dried. Numerous amine groups, carboxyl groups, and oxygen-containing functional groups were present on the surfaces of the three BN-CDs that had been prepared, and these groups could interact with the hydroxyl groups on the surface of cotton fabrics to improve the engagement between BN-CDs and cotton fabrics. [52].

Under 365 nm UV light, these BN-CDs generate blue and green-blue luminescence and display high absorption peaks. Their PL behavior was independent of the excitation wavelength. The greatest performance was observed on the cloth treated with BN-CDs utilizing citric acid as the carbon source. The fabric's UV protection factor UPF value was 50.1 after ten pieces of washing, with decent shape and elasticity. [52].

3.4.2. Nanocoating on cotton fabrics with nitrogen-doped carbon quantum dots/TiO₂/ Polyvinyl alcohol

Non-double-bonded cellulosic fibers offer a low UPF and are biodegradable and eco-friendly. Thus, treatment with various chemical UV protection agents becomes an approach to raise the UPF of these cellulosic fibers [53]. TiO₂ is extensively employed as a UV protective agent in textiles because of its excellent effectiveness, chemical stability, and light endurance. On the contrary hand, these NPs exhibit little to no filtering in the visible area, which results in a smaller scattering impact [54]

B.H.S. Felipe et al. considered adding carbonaceous nanostructures like graphene to TiO₂ NPs, which have produced excellent UV protection for textiles and are one method for resolving this issue. Additionally, graphene had significant UVA/UVB spectrum absorption. When doped with nitrogen, the material also exhibits remarkable efficiency, stability, and biocompatibility. Moreover, this doping offers excellent quantum yield and extraordinary UV absorption capabilities for GQD produced from citric acid. Furthermore, it has been established that GQDs is a biocompatible material with minimal toxicity, even when studied in conjunction with TiO₂. [53]

Polyvinyl alcohol (PVA) was used as a binder because of its attraction for the available hydroxyls in cotton, which allows it to produce hydrogen bonds with cotton, causing the creation of a light coating of the substance on the surface of cotton fibers. TiO₂/N-GQD NPs were used to create the nano-coatings that could be applied on bleached cotton fabric. [53]

When compared, uncoated textiles displayed little protection, but fabrics that were loaded with nano-

coatings of TiO₂/N-GQD produced significant UV protection factors (UPF) up to +50, demonstrating their efficacy. Furthermore, they survive up to 20 washings without losing UPF. [53].

Table 1: The effectiveness of QC-CDs@PU doped with various QC-CD concentrations in absorbing UVA and UVB radiation [55]

QC-CDs@PU	Integral area in UVA	Absorption rate in UVA
Pure PU	6772.25	15.3%
10 mg/mL QC-CDs@PU	3695.4	53.8%
20 mg/mL QC-CDs@PU	1915	76.1%
30 mg/mL QC-CDs@PU	900.325	88.7%
40 mg/mL QC-CDs@PU	138.675	98.2%

Table 2: The effectiveness of BP-4@PU doped with various doses of BP-4 in UVA and UVB for UV absorption [55].

BP-4@PU	Integral area in UVA	Absorption rate in UVA
Pure PU	6772.25	15.3%
10 mg/mLBP-4@PU	5339.1	33.3%
20 mg/mLBP-4@PU	3889.725	51.4%
30 mg/mLBP-4@PU	3379.3	57.7%
40 mg/mLBP-4@PU	2690.675	66.4%

3.4.3. Quercetin-CDs as UV-absorbents

Significant progress has been made in the field of functional textiles thanks to polyurethane. The PU-coated fabric surface displayed a variety of properties, including self-cleaning, anti-sticking, and anti-contamination, as well as its uses in textile finishing. [56]

Since UVA radiation is known to be harmful to the human body and skin, it also affects colored materials by causing the degradation and fading of colors. As a result, UV absorbents were created. There are two types of UV absorbers: organic and inorganic. Organic UV absorbers mostly comprise salicylic acid, benzophenone, triazine, and other organic chemicals, but the majority of them are oil-soluble, whereas inorganic UV absorbers nearly exclusively contain alcohol as a solubilizer. The commercially available form of UV absorbers, 2-hydroxy-4-methoxy benzophenone-5- sulfonic acid, dissolves in water (BP-4). Cons of this class of absorbers are their high cost, toxicity, and limited range of absorption. [55].

In a conclusion, quercetin, a flavonoid present in the flowers, leaves, buds, and fruits of many plants, was adopted by Z. Xu et al. to create CDs. A straightforward, one-step hydrothermal synthesis process was used to create QC-CDs, which not only completely absorb UV radiation but also don't interfere with the transmission of visible light. The created QC-CDs exhibit good stability and photobleaching endurance. Compared to the commercial organic UV absorber BP-4 is water soluble. Additionally, they can absorb UV radiation in both acidic and alkaline environments and have a larger UV absorption spectrum. [55].

In UV absorption systems of waterborne coatings PU, QC-CDs were effectively used. In addition to not altering the PU's inherent characteristics, the inclusion of QC-CDs also gives it complete UV absorption qualities. It was shown that the treated dye with BO-4@PU showed a partly photodegradation in contrast to the treated dye with QC-CDs@PU when Rhodamine B was wrapped with QC-CDs@PU and BP-4@PU, respectively, under continuous 365 UV irradiation. (Table 1) shows the UV absorption efficiency of QC-CDs@PU doped with various QC-CD concentrations at UVA and UVB, and (Table 2) displays the UV absorption efficiency of BP-4@PU doped with various BP-4 concentrations at UVA and UVB. QC-CDs have the potential to usher in a new age of water-soluble UV absorbers due to their straightforward, affordable, safe, and ecologically friendly manufacturing method. [55].

3.5. CDs for dye wastewater

3.5.1. Carbon quantum dots (CQDs) for constructing loose nanofiltration membranes

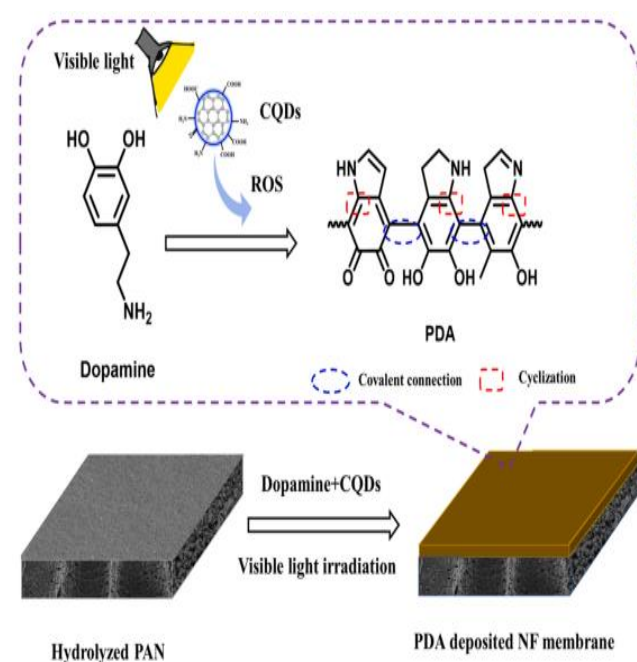
The textile industries release a significant volume of extremely salty textile effluent, endangering human health and the environment. Although salts are thought of as a bioresource, they are damaging to the biodegradation treatment of textile wastewater. Therefore, in the treatment of textile wastewater, the efficient detachment of dye/salt combination is quite important. Because of its capabilities for high efficiency, low cost, seamless implementation, and adaptability, nanofiltration (NF) is viewed as a viable method to create safe water [57].

Nevertheless, the thick selective layer of the NF membranes may be able to exclude both the dye and the salt, necessitating the use of polydopamine (PDA). The PDA layer is created by oxidative polymerization in an alkaline environment, and it may deposit on a variety of surfaces without causing structural damage. Additionally, PDA-derived functional groups like amine and catechol make it simple to further functionalize the surface by covalently connecting molecules or chelating metal ions, giving the modified NF membranes even more advantageous characteristics. [57].

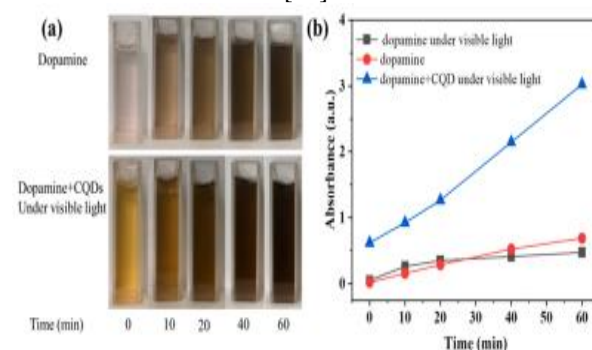
The creation of PDA is often an unregulated process without the controlled growth of PDA coating because aggregation into nanoparticles and surface polymerization fight for space. The oxygen diffusion barrier's decreased ability to produce dopamine oxidation has led to this extensive operation. Additionally, it requires a lot of time a few hours to a few days—which makes it essential for improving the PDA coatings. [57].

By pyrolyzing lysine, Y.-F. Mi and colleagues were able to create CQDs that included nitrogen. After that, the produced CQDs were coated onto polyacrylonitrile (PAN) and added to the dopamine

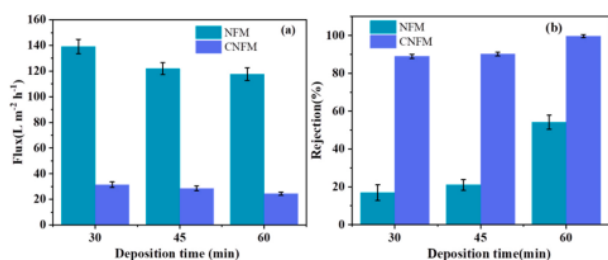
solution to produce improved NF membranes. In the presence of UV radiation, CQDs significantly increased the oxidation of dopamine, leading to oxidative polymerization. This was accomplished by producing enough reactive oxygen sources (ROS) which are displayed in (Scheme 8). The color nuances and UV-vis absorbance were shown in a reaction time graph in (Scheme 9). The presence of CQDs caused the dopamine solution to quickly generate PDA, which is why it turned dark black after 40 minutes and displayed a darker solution color than the original dopamine solution. When dopamine was dissolved in a solution containing CQDs, the absorbance at 420 nm increased dramatically linearly. Contrarily, a steady rise in absorbance was seen in the dopamine solution devoid of CQDs. [57].



Scheme 8: Dopamine deposition triggered by CQDs [57].



Scheme 9: (a) Images of the original dopamine solution and the dopamine solution including CQDs (2 mg mL⁻¹) and (b) Time-dependent absorbance at 420 nm for the original dopamine solution with or without visible light irradiation and the mixture of dopamine and CQDs solution when exposed to visible light [57].



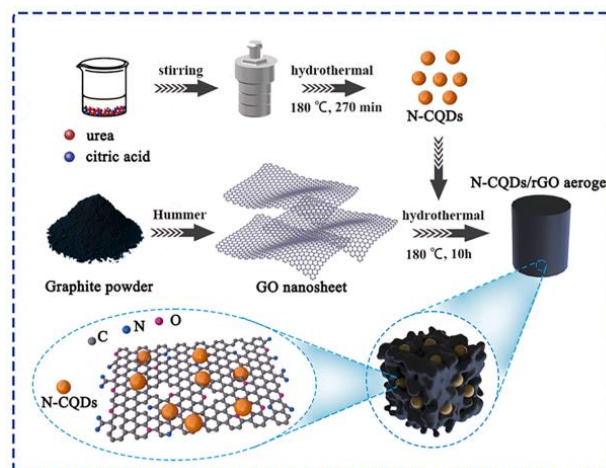
Scheme 10: NFM and CNFM at varied deposition durations (CQDs: 2 mg mL⁻¹), water flux (a), and MYB dye rejection (b); DA's effects include Water flow and CQDs mass ratio [57].

With different preparation circumstances, such as deposition duration and the mass ratio of DA: CQDs, the NF separation performance of CNFM was measured. as shown in (scheme. 10a-b), The CQDs induced PDA coating membrane (i.e., CNFM), as compared to NFM, had a much greater dye rejection during the same deposition period. It showed that NF membranes with fewer flaws may be formed when CQDs were added to a dopamine solution. Additionally, by using various deposition periods, the separation performance of CNFM may be adjusted. The MYB rejection rose dramatically from 88.9% to 99.7% with the extended deposition period, and when filtrated with MYB/NaCl mixed solution CNFM-60 -60 mins-, it demonstrated strong selectivity between dye and salt as well as good antifouling performance. Also, the smooth and integrated coating layer may be formed by the PDA that is initiated by CQDs covering the whole PAN surface. Poor homogeneity of the PDA coating results from the sluggish oxidative polymerization rate of air-oxidized dopamine, which is insufficient to create enough PDA nanoparticles to completely cover the PAN surface. In addition, the PDA nanoparticles will grow into bigger particles, which will make the PDA covering even rougher [57]. The results of the experiments showed the huge impact of CQDs in the improvement of PDA coatings.

3.5.2. Implanting Nitrogen-doped carbon quantum dots (CQDs) into reduced graphene oxide aerogels

Given their low density, significant electrical conductivity, and outstanding dielectric behavior, carbonaceous materials, particularly reduced graphene oxide (rGO), have attracted a lot of attention recently. Interestingly, materials based on CQDs also demonstrate their use in electromagnetic absorbance. Therefore, developing an N-doped CQD and implanting it into rGO aerogel to create a 3D structure was suggested. rGO can often be utilized to absorb the pollutants in wastewater because of its sheet-like structure, delocalized π -electron system, and oxygen-containing functional groups on its surface. Additionally, it appears that the N-CQDs/rGO displays preferential adsorption for cation and anion dye. [58].

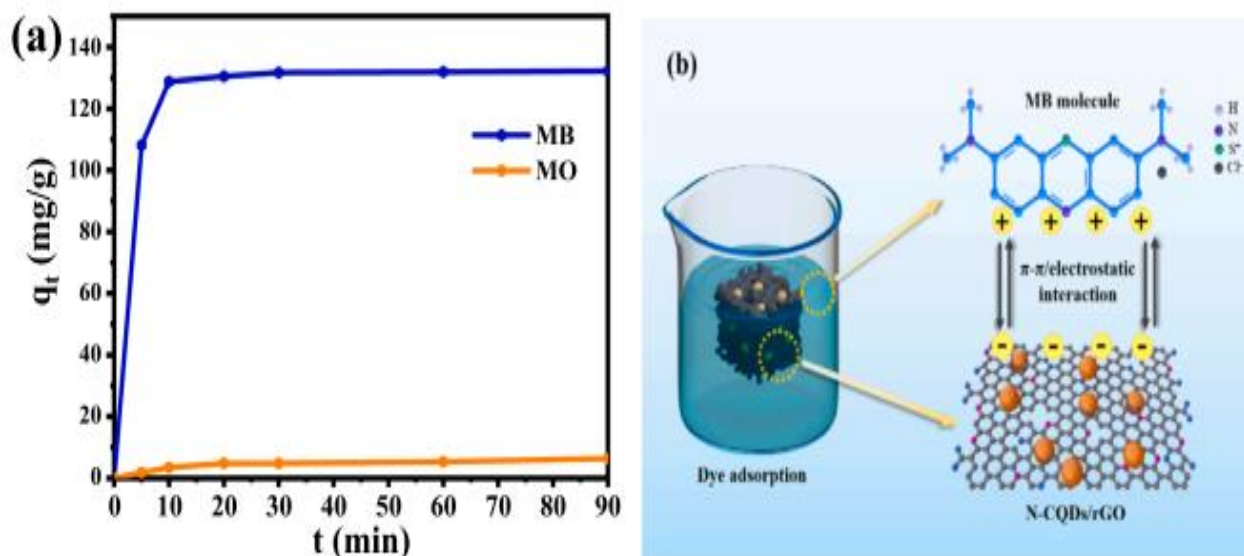
As demonstrated in (Scheme 11), the N-CQDs/rGO composites were created using a simple, inexpensive, and environmentally acceptable synthetic method. J. Qiu et al. produced luminous N-doped carbon quantum dots by hydrothermal technique utilizing citric acid as the carbon source and urea as the nitrogen source, while graphene oxide (GO) was produced using Hummers' procedure [59]. Additionally, the remaining urea in the N-CQDs solution might result in a reduction of GO during the hydrothermal treatment. The N-CQDs/rGO aerogels were then produced. [58].



Scheme 11: Representation of the three-dimensional N-CQDs/rGO hierarchical porous aerogel's synthesis process [58].

The application of CQDs to rGO lowers the graphitization level and raises the defect degree, both of which are advantageous for producing more active sites on the surface and increasing the composite's capacity for dye adsorption. indicating that N-CQDs produce more functional groups containing oxygen. [58]. Moreover, the ability of the generated N-CQDs/rGO composites to adsorb the cationic dye MB and the anionic dye MO was explored. The MB and MO adsorption curves onto the composite at multiple interaction times are shown in (Scheme 12a). Due to a large number of active sites on the surface, visible fast adsorption may be observed during the first 10 minutes. In contrast to MO, which has an equilibrium adsorption capacity of just 6.15 mg/g, MB dye has a greater adsorption capacity of 132.22 mg/g. [58].

The negatively charged oxygen-containing functional groups, such as hydroxyl, carboxyl, and aldehyde groups, that are found on the surface of rGO are advantageous for the adsorption of the cationic dye due to the electrostatic association, as was previously indicated. MO is an anionic dye, whereas MB is a cationic dye.



Scheme 12: (a) The sample N-CQDs/ability rGO's to adsorb MB and MO, (b) a schematic depiction of the N-CQDs/rGO aerogels' ability to adsorb MB dye [58].

Thus, the aforementioned difference in adsorption capacity for MB and MO may be mostly driven by the electrostatic interaction and π - π conjugation, in addition to the sizeable pore structure and particular surface area. In the meanwhile, the MB dye's adsorption process was demonstrated in (Scheme 12b). Additionally, the as-synthesized N-CQDs/rGO composite has the highest adsorption capacity of 261.8 gm/g^{-1} which indicates that it is a potential candidate for cation dye adsorption. [58].

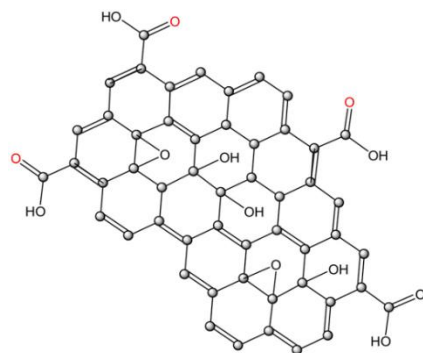
3.5.3. Embedding Polyvinyl chloride with carbon quantum dots (CQDs)

Owing to PVC's hydrophobic properties, using it as a filtering system has several drawbacks, such as decreased penetration flow, decreased system performance, and increased membrane cleaning costs. Therefore, to be employed for industrial purposes, such a membrane needs to be changed. And due to the distinct characteristics of nanoparticles, they may be utilized to change and enhance the characteristics of filters, such as their hydrophilicity and porosity [35]. Citric acid was pyrolyzed to create CQDs, and membranes were created using the phase inversion approach by V. Vatanpour et al. The GQDs exhibit the usual stretching vibrations of the functional groups' hydroxyl and carboxyl that were present in the GQDs structure. (Scheme 13). The effects of mixing the nanoparticles with PVC were then studied. It is clear from dispersing nanoparticles that introducing hydrophilic GQDs in solution considerably speeds up the water diffusion from the coagulation bath to the polymer film (quicker rate of transfer between solvent and non-solvent), which results in the formation of big finger-like or macro-voids and increases the porosity together with the size of cavities. The amount of free space that is occupied by the membrane body's total volume increases with pore size, which might lead to an

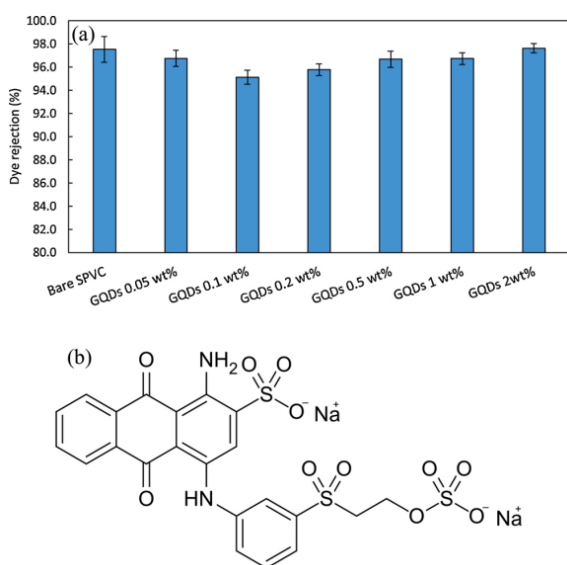
improvement in porosity. By examining the phase inversion process through the membrane coagulation in non-solvent, this alteration in membrane porosity could be examined. In general, it is also acknowledged that kinetics and thermodynamics are two driving factors that may be adjusted to change how phase separation membranes are formed. [60]

Several hydrophilic groups in the GQDs' structure could interact with polymer chains. Additionally, because the GQDs nanoparticles are naturally hydrophilic, the hydrophilicity increased when additional nanoparticles were added. Additionally, it was demonstrated that the GQD application improved tensile strength, which is connected to the reinforcing influence of nanomaterial additives in the polymer matrix. Hydrogen bonding between the functional groups (OH, -COOH, etc.) of the nanomaterial and polymer may be the cause of how hydrophilic nanoparticles reduce the surface roughness of polymeric membranes. By reducing surface roughness, the likelihood of contaminants congregating in the membrane's upper valleys is reduced. [60].

The filtration outcomes with colored contaminants are displayed in (Scheme 14). Reactive Blue 19 dye (Scheme 14b) was dissolved in a solution with a pH of 5.76 and a concentration of 100 mg/L. All membrane rejection rates were more than 95%, demonstrating exceptional nanofiltration capability. With a rejection rate of 97.6%, the GQDs 2 wt% sample has the greatest rejection rate and is therefore the best choice for colour removal. Additionally, it was demonstrated that adding 1 wt% GQDs boosted the pure water flow from 12.1 to 19.4 L/m² h [60]. It is determined how significant CQDs are in the treatment and filtering of textile wastewater by their above-average good behaviours.



Scheme 13: Schematic representation of the GQDs structure [35].



Scheme 14: b) the structure of Reactive Blue 19, and (a) dye rejection.[60]

Conclusion

A facile review demonstrated the synthesis of CDs based on their applications and types. There are several fabrications of CDs varying from green synthesis to synthetic synthesis. CDs are widely used in the textile industry as they are used as sensors/adsorbents for toxic metals and materials that threaten humans' health critically such as Cr (VI) and Fe³⁺, as well as leaving a mark in the medical field by being immobilized in cotton masks and work as sensors for acetone resulting in helping diabetic patients. CDs also are utilized as flame-retardants by enhancing materials used in suppressing combustions and helping improve their application. In addition, CDs are also used broadly as antimicrobial agents due to their antimicrobial properties, their role in cultivating Ag's performance is impeccable as well as their use in PET membranes and military clothes. Likewise, CDs are used as UV blockers/absorbents whether enhancing the performance of TiO₂ or working

individually such as Quercetin-CDs in addition to Boron and co-doped CDs.

CDs have been utilized additionally in the treatment of wastewater by improving nanofiltration membranes and, absorbents of pollutants.

Overall CDs are very important in the textile industry with their great performance and features leaving a rich impact in nearly everything related to the industry with the potential of offering more.

References

1. de Oliveira, C.R.S., et al., *Use of advanced materials in smart textile manufacturing*. Materials Letters, 2022: p. 132047.
2. Syduzzaman, M., et al., *Smart Textiles and Nano-Technology: A General Overview*. Textile Science & Engineering, 2015. **5**(1).
3. Hassabo, A.G. and A.L. Mohamed, *Enhancement of Thermo-Regulating Textile Materials Using Phase Change Material (PCM)*. Evolution in Polymer Technology Journal, 2019. **2**(1): p. 180009 (1-11).
4. Hassabo, A.G., et al., *Chromic Dyes for SMART Textile: A Review*. Letters in Applied NanoBioScience, 2023. **12**(4): p. LIANBS124.161.
5. Mohamed, A.L., T.A. Khattab, and A.G. Hassabo, *Color-tunable encapsulated perylene-labeled silica fluorescent hybrid nanoparticles*. Results in Chemistry, 2023. **5**: p. 100769.
6. Mohamed, M., et al., *SMART Textiles via Photochromic and Thermochromic Colorant*. Journal of Textiles, Coloration and Polymer Science, 2022. **19**(2): p. 235-243.
7. Saad, F., et al., *Intelligent Wound Dressing Textile Fabric Using Various SMART Materials*. Materials International, Accept 2023.
8. Zayed, M., et al., *Psidium Guajava Leave Extract for Improving Ultraviolet Protection and Antibacterial Properties of Cellulosic Fabrics*. Biointerface Research in Applied Chemistry, 2022. **12**(3): p. 3811 - 3835.
9. Zayed, M., et al., *Synthesis of different nanometals using Citrus Sinensis peel (orange peel) waste extraction for valuable functionalization of cotton fabric*. Chemical Papers, 2022. **76**(2): p. 639-660.
10. Ehab, A., et al., *Antimicrobial and Blood-Repellent Finishes of Surgical Gowns*. Journal of Textiles, Coloration and Polymer Science, 2023. **20**(1): p. 131-135.
11. Fathallah, A.I., et al., *Intelligent PCM composite for enhancing the thermoregulated properties of Different cotton/Polyester Fabric Constructions*. Journal of Textiles, Coloration and Polymer Science, 2023. **20**(1): p. 113-123.
12. Fathallah, A.I., et al., *Alginate/Stearic/Octadecane as Phase Change Material (PCM) for enhancing the thermal Comfort-ability of Different Polyester Fabrics Constructions*. Egyptian Journal of Chemistry, 2023: p. -.

13. Hassabo, A.G., et al., *Applications of Nanotechnology in the Creation of Smart Sportswear for Enhanced Sports Performance: Efficiency and Comfort*. Journal of Textiles, Coloration and Polymer Science, 2023. **20**(1): p. 11-28.
14. Hassabo, A.G., et al., *SMART Wearable Fabric using Electronic Textiles – A Review*. Journal of Textiles, Coloration and Polymer Science, 2023. **20**(1): p. 29-39.
15. Hassabo, A.G., et al., *Enhancing Printability of Natural Fabrics via Pre-treatment with Polycationic Polymers*. Egyptian Journal of Chemistry, 2023. **66**(2): p. 167-181.
16. Hassabo, A.G., et al., *Synthesis of AgNPs and ZnONPs using tea leaves extract and their utilization to improve dyeability, printability and functionality of cotton and wool fabrics*. Inorganic Chemistry Communications, 2023. **150**: p. 110525.
17. Mohamed, A.L., et al., *Mesoporous silica encapsulating ZnS nanoparticles doped Cu or Mn ions for warning clothes*. Results in Chemistry, 2023. **5**: p. 100689.
18. Yasser, A., et al., *Multifunctional Properties of Cotton Fabric Treated with Chitosan and RTV Silicone*. Journal of Textiles, Coloration and Polymer Science, 2023. **20**(1): p. 125-130.
19. Zayed, M., et al., *Recent developments in the utilization of polymer nanocomposites in textile applications*. Journal of Textiles, Coloration and Polymer Science, 2023: p. -.
20. Hassabo, A.G., et al., *Review on Some Fabric Pretreatment via Plasma to Improve their Printability using Various Types of Colorants and Dyes*. Materials International, Accept 2022.
21. Saad, F., et al., *Polyurethane and its Application in Textile Industry*. Letters in Applied NanoBioScience, Accept 2023.
22. Morsy, M., A. Elzawy, and M. Oraby, *Carbon Nano Based Materials and Their Composites for Gas Sensing Applications: Review*. Egyptian Journal of Chemistry, 2022. **65**(5): p. 691-714.
23. Zaib, M., et al., *Green Synthesis of Carbon Dots and Their Application as Photocatalyst in Dye Degradation Studies*. Arabian Journal for Science and Engineering, 2020. **46**(1): p. 437-446.
24. Liu, J., R. Li, and B. Yang, *Carbon Dots: A New Type of Carbon-Based Nanomaterial with Wide Applications*. ACS Central Science, 2020. **6**(12): p. 2179-2195.
25. Zhang, L., et al., *Dual-emitting film with cellulose nanocrystal-assisted carbon dots grafted SrAl₂(2)O₄, Eu(2+), Dy(3+) phosphors for temperature sensing*. Carbohydr Polym, 2019. **206**: p. 767-777.
26. Khattab, T.A. and M.S. Abdelrahman, *From Smart Materials to Chromic Textiles*, in *Advances in Functional Finishing of Textiles*, M. Shahid and R. Adivarekar, Editors. 2020, Springer Singapore: Singapore. p. 257-274.
27. Ahmed, E., et al., *Development of functional glow-in-the-dark photoluminescence linen fabrics with ultraviolet sensing and shielding*. Luminescence, 2022. **37**(8): p. 1376-1386.
28. Al-Qahtani, S.D., et al., *Development of fluorescent carbon dots ink from rice straw waste toward security authentication*. Journal of Molecular Liquids, 2022. **354**: p. 118927.
29. Liu, J., T. Kong, and H.-M. Xiong, *Mulberry-Leaves-Derived Red-Emissive Carbon Dots for Feeding Silkworms to Produce Brightly Fluorescent Silk*. Advanced Materials, 2022. **34**(16): p. 2200152.
30. G. Ashok Varman, K.K.a.P.N., *Green synthesis of fluorescent carbon dots from canon ball fruit for sensitive detection of Fe³⁺ and catalytic reduction of textile dyes*. Dyes and Pigments, 2022. **199**: p. 11.
31. Arul, V. and M.G. Sethuraman, *Hydrothermally Green Synthesized Nitrogen-Doped Carbon Dots from Phyllanthus emblica and Their Catalytic Ability in the Detoxification of Textile Effluents*. ACS Omega, 2019. **4**(2): p. 3449-3457.
32. Fatahi, Z., N. Esfandiari, and Z. Ranjbar, *A New Anti-counterfeiting Feature Relying on Invisible Non-toxic Fluorescent Carbon Dots*. Journal of Analysis and Testing, 2020. **4**: p. 307-315.
33. Salimi, F., et al., *Optimization and characterization of eco-friendly antimicrobial nanocellulose sheet prepared using carbon dots of white mulberry (Morus alba L.)*. Journal of the Science of Food and Agriculture, 2021. **101**(8): p. 3439-3447.
34. Sun, Z., et al., *Origin of green luminescence in carbon quantum dots: specific emission bands originate from oxidized carbon groups*. New Journal of Chemistry, 2018. **42**(6): p. 4603-4611.
35. Vadivel, R., et al., *Synthesis of highly luminescent carbon dots from postconsumer waste silkcloth and investigation of its electron transfer dynamics with methylviologen dichloride*. Journal of the Indian Chemical Society, 2021. **98**: p. 7.
36. Devi, P., et al., *Metal ion sensing and light activated antimicrobial activity of aloe-vera derived carbon dots*. Journal of Materials Science: Materials in Electronics, 2018. **29**(8): p. 17254-17261.
37. Hu, T., et al., *Multifunctional chitosan non-woven fabrics modified with terylene carbon dots for selective detection and efficient adsorption of Cr(VI)*. Chemical Engineering Journal, 2022. **134202**.
38. Rani, U.A., et al., *A review of carbon quantum dots and their applications in wastewater treatment*. Advances in Colloid and Interface Science, 2020. **278**: p. 102124.
39. Emam, H.E., et al., *Potential military cotton textiles composed of carbon quantum dots clustered from 4-(2,4-dichlorophenyl)-6-oxo-2-*

- thioxohexahydropyrimidine-5-carbonitrile*. Cellulose, 2021. **28**(15): p. 9991-10011.
40. Haque, E., et al., *Recent Advances in Graphene Quantum Dots: Synthesis, Properties, and Applications*. Small Methods, 2018. **2**(10): p. 1800050.
 41. ElKhouly, S.M. and N.A. Fathy, *A review on nano-carbon materials for pollution remediation*. Egyptian Journal of Chemistry, 2021. **64**(12): p. 7029-7052.
 42. Abd Elkhalk, A.A., et al., *A minireview on Applications of the Metal-Organic Framework and Carbon Dots in Dye Photodegradation to Protect the Aquatic Environment from Organic Pollutants*. Egyptian Journal of Chemistry, 2021. **64**(11): p. 6161-6180.
 43. Mogharbel, A.T., et al., *Development of a "Turn-off" fluorescent sensor for acetone from rice straw-derived carbon dots immobilized onto textile cotton mask*. Journal of Molecular Liquids, 2022. **362**: p. 119666.
 44. Xue, B., et al., *Construction of a P-N-Si flame retardant coating on the cotton fabric with the integration of biomass carbon dots and ammonium polyphosphate*. Research Square, 2022.
 45. Gu, W., et al., *Functionalization of PET with carbon dots as copolymerizable flame retardants for the excellent smoke suppressants and mechanical properties*. Polymer Degradation and Stability, 2022. **195**: p. 109766.
 46. Martín, C., J.C. Ronda, and V. Cádiz, *Boron-containing novolac resins as flame retardant materials*. Polymer Degradation and Stability, 2006. **91**(4): p. 747-754.
 47. Kamel, S., et al., *Graphene's Structure, Synthesis, and Characterization; a brief review*. Egyptian Journal of Chemistry, 2019. **62**(Special Issue (Part 2) Innovation in Chemistry): p. 593-608.
 48. Khose, R.V., et al., *Novel approach towards the synthesis of carbon-based transparent highly effective flame retardant*. Carbon, 2018. **139**: p. 205-209.
 49. Teymourinia, H., O. Amiri, and M. Salavati-Niasari, *Synthesis and characterization of cotton-silver-graphene quantum dots (cotton/Ag/GQDs) nanocomposite as a new antibacterial nanopad*. Chemosphere, 2021. **267**: p. 129293.
 50. Koulivand, H., et al., *Novel antifouling and antibacterial polyethersulfone membrane prepared by embedding nitrogen-doped carbon dots for efficient salt and dye rejection*. Materials Science and Engineering: C, 2020. **111**: p. 110787.
 51. Travlou, N.A., et al., *S- and N-doped carbon quantum dots: Surface chemistry dependent antibacterial activity*. Carbon, 2018. **135**: p. 104-111.
 52. Cheng, S., et al., *Study on the ultraviolet absorbing properties of cotton fabric finished with boron and nitrogen co-doped carbon dots*. Journal of Coatings Technology and Research, 2022. **19**(4): p. 1077-1086.
 53. Felipe, B.H.S., et al., *Nanocoating on cotton fabric with nitrogen-doped graphene quantum dots/titanium dioxide/PVA: an erythematous UV protection and photoluminescent finishing*. Journal of Materials Research and Technology, 2022. **18**: p. 2435-2450.
 54. Bouazizi, N., et al., *Development of new composite fibers with excellent UV radiation protection*. Physica E: Low-dimensional Systems and Nanostructures, 2020. **118**: p. 113905.
 55. Xu, Z., et al., *Preparation of new full UV-absorbing carbon dots from quercetin and their application in UV-absorbing systems for waterborne polyurethane coatings*. Materials Today Chemistry, 2023. **27**: p. 101269.
 56. Sikdar, P., et al., *Polyurethane (PU) based multifunctional materials: Emerging paradigm for functional textiles, smart, and biomedical applications*. Journal of Applied Polymer Science, 2022. **139**(38): p. e52832.
 57. Mi, Y.-F., et al., *Promoted deposition of polydopamine by carbon quantum dots to construct loose nanofiltration membranes*. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2023. **660**: p. 130871.
 58. Qiu, J., et al., *Implanting N-doped CQDs into rGO aerogels with diversified applications in microwave absorption and wastewater treatment*. Chemical Engineering Journal, 2022. **443**: p. 136475.
 59. Wang, W., et al., *A novel poly(m-phenylenediamine)/reduced graphene oxide/nickel ferrite magnetic adsorbent with excellent removal ability of dyes and Cr(VI)*. Journal of Alloys and Compounds, 2017. **722**: p. 532-543.
 60. Vatanpour, V., et al., *Anti-fouling and permeable polyvinyl chloride nanofiltration membranes embedded by hydrophilic graphene quantum dots for dye wastewater treatment*. Journal of Water Process Engineering, 2020. **38**: p. 101652.