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Carbon-based material derived from biomass waste for wastewater treatment

Muhammad Shamil Soffian [a], Faezrul Zackry Abdul Halim [a], Farhana Aziz [b], Mukhlis A . Rahman [b], Mohamed Afizal Mohamed Amin [c], Dayang Norafizan Awang Chee [a,*]

[a] Faculty Resource Science and Technology, Universiti Malaysia Sarawak, Kota Samarahan 94300, Sarawak, Malaysia
[b] Advanced Membrane Technology Research Centre (AMTEC), School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor Darul Takzim 81310, Malaysia
[c] Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak, Kota Samarahan, Sarawak 94300, Malaysia

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ABSTRACT

Biomass waste has known as a new precursor for the production of carbon-based materials due to its carbon richness, low cost, ease to access, ubiquitous, renewable and environmental-friendliness. In this publication, the study on the availability of biomass waste and the carbon-based materials (CBMs) for wastewater treatment application is reviewed and addressed. This paper discussed several types of CBMs such as activated carbon, graphene, carbon nanotubes, biochar, and carbon aerogel. The production of these different CBMs and their modification are given special attention. As harmful organic, dyes, and inorganic pollutants emerging from the wastewater has caused damage to the environment and water supplies, adsorption is the most widely utilised conventional technology for the removal of hazardous pollutants due to its ease of use and relatively cheap in comparison with other emerging methods. This corresponds to the CBMs which mainly works on the adsorption mechanism to perform the wastewater treatment. There are three kinds of biomass waste being explained which are sewage sludge, lignocellulosic, and cotton-based waste. This paper also extensively summarised a multitude of aspects regarding the biomass waste and the CBMs derivation from biomass waste. The challenges on the synthesis of CBMs from biomass was also included. In summary, the conclusion and future direction of the research were also discussed.

1. Introduction

Hazardous materials existed in polluted water has become a significant threat to public health and also leads to the water shortage (Abd Elkodous et al., 2021). Water is generally contaminated by the industrial effluent or an unavailability of sufficient proper sanitation establishment. In the twenty-first century, the increase in the industrial activities and human population have created a severe and long-term threat to water supplies (Li et al., 2021). According to the World Health Organization, over than 1.2 billion people have caused fatality as a consequence of drinking contaminated water, and this number is likely to rise considerably in the future years owing to the rising of water pollution (Wilson, George and Jose, 2018). Water pollution is also caused by irresponsible human behaviour, such as the dumping of trash into water resources, such as to a river or a lake (Thines et al., 2017). As matter of fact, high population expansion in developing nations will tend to escalate the need for clean water thus the urge to treat the industrial wastewater (Sadegh and Ali, 2018).

Numerous technologies and industrial procedures for wastewater purification or management have been designed and implemented rapidly over the last few years to lessen the risks of water contamination to humans (Jiao et al., 2017). Adsorption technology have gained a lot of interest as an alternative for treating refractory wastewaters (Bello and Raman, 2019). According to Sabzehmeidani *et al.* (Sabzehmeidani et al., 2021), one compelling alternative is the wastewater treatment from industries through adsorption method for enhancing its quality to be used in agricultural and industrial operations. Metal ions, dyes, pharmaceutical and personal care products, organic contaminants such as hydrocarbons, pesticides, fertilizers, phenols, plasticizers, biphenyls, detergents, oils, medicines, greases, proteins, and carbohydrates are indeed pollutants that are acquired by adsorption (Wong et al., 2018). In the last decades, considerable investigation effort has been increase to

* Corresponding author.
E-mail address: dnorafizan@unimas.my (D.N. Awang Chee).

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further determine the excellent attributes of material for the adsorption of harmful and hazardous chemicals. Therefore, the various categories of materials have been reviewed, and the scope of this manuscript is to present a comprehensive and all-encompassing perspective on the topic of carbon-based materials obtained from biomass for wastewaters treatment applications along with the newest procedures, techniques and materials.. Various types of carbon-based materials are reviewed to compare the synthesis approaches for the materials, along with their limitations.

2. Wastewater

Water pollution is one of the most prominent types of pollution generated by various sources such as industrial, household, sewage, hazardous chemicals, municipal effluent, clinical waste, industrial waste, and so on. As a consequence, the effects of wastewater has caused fear among the public (Nahiun, 2021). Studies on water contamination caused by new pollutants such as pharmaceuticals have received not received great attention in recent years. (Streit et al., 2021). These pollutants products are being generated at a quick pace to satisfy the expanding demands of human populations across the world, which are increasing as well as ageing (Fröhlich et al., 2018), due to the huge number of medical treatments and the availability of medicines (Zeng et al., 2018). The pharmaceutical industries lead to a continuous outflow of pharmaceutical pollutants, since a significant portion is released without further treatment into the ecosystem and these compounds are unable to be removed by regular treatment procedures (Comber et al., 2018). Ibuprofen, ketoprofen, and paracetamol are among some of the non-steroidal anti-inflammatory medicinal substances that are commonly found in water sources (Ahmed, 2017,Sellaoui et al., 2017).

On the other hand, oil-contaminated wastewater has been identified as one of the most dangerous pollution sources. Crude oil production, oil refineries, the petrochemical sector, metal processing, compressors condensates, vehicle washing, lubricants, and cooling agents are all contributors of this type of wastewater effluent (Al-Anzi and Siang, 2017). Oily wastewater is classified as high-risk industrial wastewater as it comprises toxic chemicals including phenols, petroleum hydrocarbons, and polyaromatic hydrocarbons, which are growth inhibitors for plants and animals and pose mutagenic and carcinogenic hazards to people (Al-Anzi and Siang, 2017). Serious threats to human health, terrestrial and aquatic life forms have been established due to the presence of toxic heavy metal ions and organic dyes from wastewater originating from tannery, textile, cosmetic, paper and battery, mining, printing, electroplating, and paint activities as well as toxic metal and organic pollutants to the water environments (Fu et al., 2018). Organic pollutant hydrocarbons with low polarity, such as polycyclic aromatic hydrocarbons (PAHs), are less soluble in water but highly soluble in fats. Environmental processes quickly degrade molecules containing such heteroatoms, making them less durable. Organometallic compounds, which contain metals such as lead and tin, fall into the third category. Wastes released during industrial operations also contribute significantly to the environmental organic contamination. Moreover, agricultural practices such as pesticide spraying and industrial wastes are the primary sources of organometallic environmental contaminants (Kumar et al., 2017). Fig. 1 shows the main classification of organic pollutants.

Whilst, phenol is an organic compound that could be detected in wastewater from a variety of sectors, including refineries, petrochemicals, pesticides, pint, polymer resin, cooking operations, coal industry, and pharmaceutical. Even at low concentrations, this pollutant has a significant toxicity, giving it as one of the most dangerous chemical. Phenol has severe consequences for humans, since it may cause comas, convulsions, cyanosis, and damage to the liver, kidneys, lungs, and vascular system when inhaled, ingested, or absorbed through the skin (Lütke et al., 2019). With the fast development of the chemical industry, various types of organic pollutants such as phenols, aromatic hydrocarbons, dyes, manufactured drugs, inorganic pollutants, and pesticides from agricultural wastes are eventually released into the environment, which may lead to a range of negative environmental effects such as harming the aquatic animals and humans along with the decrease in the water quality (Dehgani et al., 2020).

Moving on now, the dyes is considered to be among the most harmful contaminant in water systems due to their mutagenic, immunogenic, carcinogenic, and teratogenic effects (Azari et al., 2019). According to their dissociation behaviour in aqueous solutions, dyes may be divided into three groups: (a) cationic (basic dyes) with protonated amine group, (non-ionic (disperse dyes), and (c) anionic (acid, reactive, and direct dyes) with negative charge mostly owing to the SO^{3-} group (Sakin Omer et al., 2018). Azo dyes have one or more azoic bonds (N=N) and may be cationic or anionic. Aside to their resistance to light, heat, and aerobic digestion, it poses serious health risks to humans, including vomiting, cyanosis, allergic reactions, and genetic mutation (Elgarahy et al., 2021). In addition, methylene blue (MB) and crystal violet (CV) are organic cationic dyes that are more harmful than anionic dyes (Sakin Omer et al., 2018). Dyes are widely utilised in a broad range of industries, including textiles, paper, colouring agents, plastic, cosmetics, leather, printing, and coatings, due to their cheap cost of production, brightness, and excellent resistance to environmental conditions (Reck et al., 2018). Dyes are optically active and observable even at low concentrations and influence on water bodies by severe effects (Elgarahy et al., 2021).

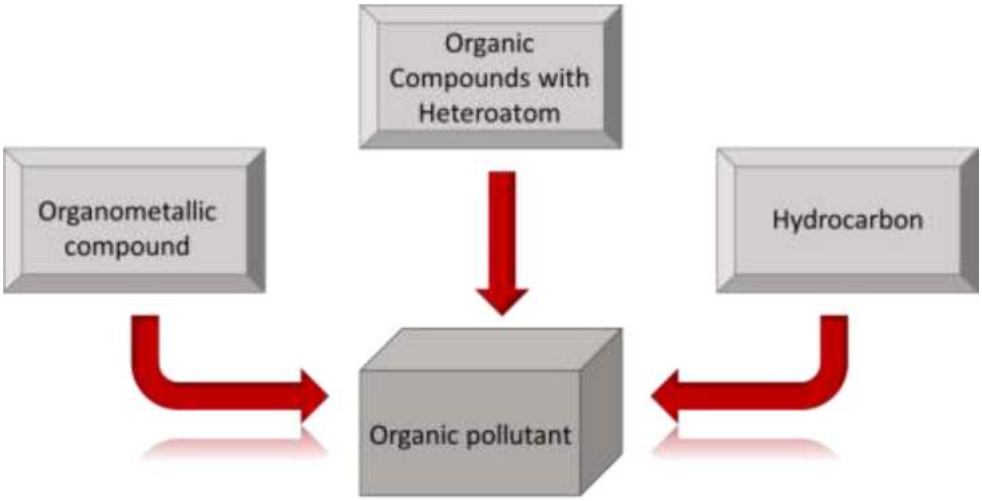

Fig. 1. Main classification of organic pollutants (Kumar et al., 2017).

Another common industrial pollutant is the heavy metal. Heavy metals is the inorganic element, with a high atomic weight and density as well as toxic even at low doses (Ali, Khan and Ilahi, 2019). Many harmful metals such are discharged into the waterways without sufficient treatment, such as As(III) Cd(II), Cu(II), Cr(VI), Ni(II), Pb(II), and Zn(II) (Dobrowolski et al., 2019). The disposal of the heavy metals may cause a major ecological imbalance owing to various adverse effects on aquatic life, and human especially carcinogenic effects, skin infections and respiratory issues via high levels of pollutants intake (Sun et al., 2020). This phenomenon not only poses a major threat to aquatic creatures and human health, but it also results in huge economic losses due to the inability to recycle heavy metal wastewater (Sun et al., 2019).

Apart from the abovementioned chemicals, other pollutants such as microplastics (MPs) also identified to present in wastewater and may become more toxic (Prata, 2018). A huge amount of plastic particles (such as plastic beads in daily chemical products, car tyre wear debris, fibres within laundry wastewater, and other fragmented plastic waste) enter the sewage drainage system, treated by the sewage treatment plant, and later discharged into the environmental water body, and eventually into the sea (Shen et al., 2022). On the source basis, MPs are divided into main and secondary microplastics. According to Hamidian *et al.* (Hamidian et al., 2021) literature, the primary source involves the particles and fibres resulting from product erosion in use, as well as the direct introduction of microplastic sized materials, such as microbeads used in cosmetics and pre-manufactured pellets. While for secondary source of MPs are formed when larger plastic items are broken down and released into the environment, which include household items, manufactured products, vehicle tyres, colour flakiness, and plastics fabrication fragmentation (Hamidian et al., 2021).

Commonly, the wastewater treatment facilities (WWTPs), which convert primary microplastics into secondary microplastics, are likely to be the dominant recipients of terrestrial microplastics before they reach natural aquatic systems (Sun et al., 2019)(Liu et al., 2021). Despite the fact that most WWTPs have been effective in removing microplastics, municipal WWTPs remain a major source of microplastics in the environment as the result of human daily regular activities, for example polyester and polyamide components (from fabric during the washing process), and personal care items like toothpaste, cleanser, and shower gel (Shen et al., 2022) (Liu et al., 2021). Furthermore, MPs (less than 5 mm) are readily transported across vast distances by water and may also act as substrates, allowing pathogens to 'hitchhike' to new ecosystems through direct effluents discharged or urban surface run-off (Ben-David et al., 2021).

2.1. Adsorption mechanism for wastewater treatment

Filtration, air flotation, precipitation, crystallization, chemical oxidation, chemical reduction, hydrolysis, ion-exchange, reserve osmosis, adsorption, extraction, and catalysis are a several of the methods available today for eliminating organic compounds from liquid mixtures (Fröhlich et al., 2018). Basically, adsorption is a physical separation technique in which solid materials are utilised to remove certain compounds from liquids or gases that might bind to the adsorbent surface via multiple mechanisms (Bello and Raman, 2019). Adsorption has been shown to be a better option due to its low-cost process for removing a wide variety of pollutants from water and wastewater, notably organic and inorganic toxins, heavy metals, dyes, pharmaceutical wastes, pesticides and other refractory pollutants. (Usman et al., 2021). Adsorption is described as a water treatment technology that effectively focuses and transfers common contaminants to other phases. The relationships between adsorbate molecules and the adsorbent are dependent on adsorption processes. Adsorption stands out owing to its effective, economical, versatile, and uncomplicated to develop and operate, emits no by-products, and requires minimal energy (Fröhlich et al., 2018). There are three forms of adsorption: physisorption (adsorbent-adsorbate interaction), chemisorption (adsorbent-solvent interaction), and electrostatic (adsorbate-solvent interaction). In brief, initial ion concentration, ionic strength, temperature, adsorbent dosage, pH value, stirring speed, coexisting ions, and contacting period are all parameters that impact the efficiency and effectiveness of adsorbents (Sadegh and Ali, 2021). It is significant to determine how adsorbent interacts with different adsorbate (i.e. heavy metal ions and dyes) in the laboratory scale to evaluate their application potential in wastewater treatment and their commitment to large scale. Nonetheless, adsorption has several disadvantages, such as the inability to attain acceptable commercial status due to a lack of appropriate adsorbents of high adsorption capacity and the lack of commercial scale columns (Sadegh and Ali, 2021). Fig. 2 depicted the advantages and disadvantages of adsorption method in the absence of suitable adsorbent.

2.2. Adsorption by carbon-based material

The solid material acted as adsorbent to serve the surface for the adsorption. The study of carbon-based nanomaterials as adsorbents has expanded in interest during the last decade (Sabzehmeidani et al., 2021). The unique characteristics and diversity of carbon-based structures, as well as the emergence of new prospects in many scientific fields of chemistry, physics, and engineering, are driving the growth of this area (Sabzehmeidani et al., 2021). A wide range of pollutants in water, including pesticides, toxic metal ions, metalloids, pharmaceuticals, and other inorganic and organic compounds, have the capability to be adsorbed by carbon-based material via a series of processes (Björklund and Li, 2017). In general, carbon is one of the most multilateral known elements in the periodic table owing to the consideration of its strength and potentiality to make bonds with other elements (Thines et al., 2017). Commercial activated carbons, graphene, and carbon nanotubes are among the most prevalent carbon-based adsorbents (Bello and Raman, 2019). The absorption efficiency of a carbon-based adsorbent for chemical compounds determined by the characteristic of the adsorbate (polarity, molecular weight, functionality, pKa, and size), the adsorbent (pore structure and size, functional groups,) and solution settings (ionic strength, temperature, and pH) (Sabzehmeidani et al., 2021). The van der Waals, induced-dipole, dipole–dipole, and hydrogen-bonding donor–acceptor forces are important for chemical compound binding and accumulation on different adsorbents in the aqueous phase. Between the diverse interactions, π–π and hydrogen bonds and also covalent and electrostatic interactions and the hydrophobic effect play are all crucial in the adsorption (Dehgani et al., 2020).

3. Carbon based materials

Generally, the carbonaceous materials have a larger ion storage capacity than graphite theoretical capacity. However, high manufacturing costs and intricate preparation methods, as well as environmental issues, are always drawbacks of nanostructured carbons. The drawbacks has encourage scientists to develop, produce, and characterize products that are more environmentally friendly (Tang et al., 2017). Carbon materials are classified as zero-dimensional nanomaterials (carbon dots and Buckminster fullerenes), one-dimensional nanomaterials (carbon nanofibers and carbon nanotubes), two-dimensional nanomaterials (graphene), and three-dimensional nanomaterials (carbon sponges) in view of their shape, size, and dimensionality (Gopinath et al., 2021). Many technologies and materials have been introduced to solve the abovementioned problems, however carbon-based materials have attracted a great attention due to their distinctive and widely flexible structures and features (Ma et al., 2017)

Having said that, porous carbons are an intriguing class of materials that comprised with various types and physical formation such as activated carbon and high surface graphite. Porous materials are another appealing carbon-based material because of their large specific surfaces, high chemical stabilities, numerous pores, unique electrical, optical,

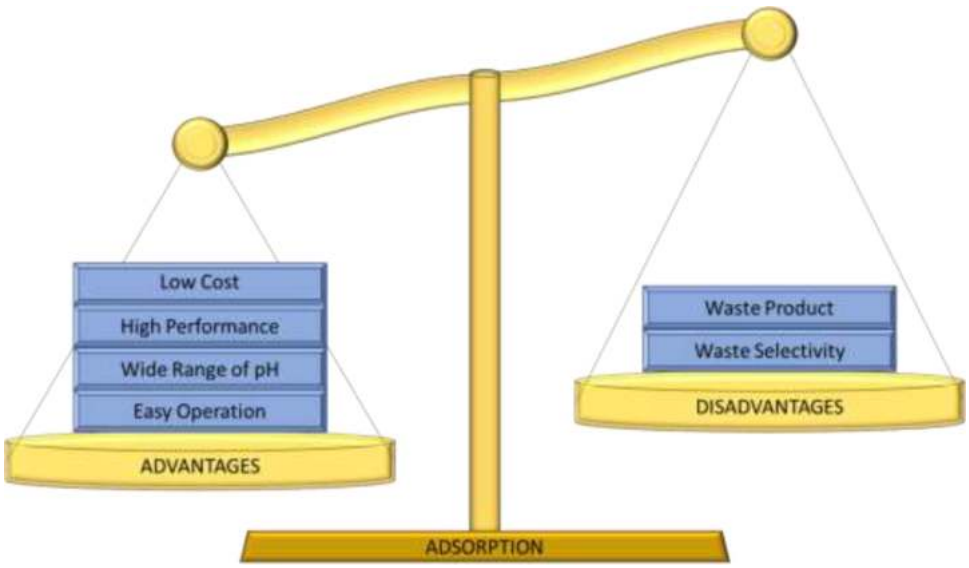

Fig. 2. The adsorption method's advantages and disadvantages in the absence of suitable adsorbent design (Sadegh and Ali, 2021).

thermal, and mechanical characteristics, and frequently greater reactivities, as well as have the advantages of an adjustable pore structure, great physical and chemical stability, a changeable specific surface, and the capacity to be easily functionalized (Ben Mosbah et al., 2020). Several porous carbon (PC) materials were used to eliminate organic chemicals and heavy metals from wastewater (Thambiliyagodage et al., 2020). The contemporary advancements in organic dye adsorption by metal-doped porous carbon materials were reviewed by Xiao *et al.* (Xiao et al., 2021) . The researchers stated that metal doping is the formation of a fine distribution of metal particles on the porous carbon exterior surface and pore channels in order to preserve the overall stability of the porous carbon surface and pore structure while also modifying the surface properties of porous carbon and thus enhancing its adsorption capability. A prominent use for porous carbon materials is the treatment of dye effluent (Chen et al., 2018). Besides, Sun *et al.* (Sun et al., 2019) demonstrated that elevated performance nitrogen-doped porous carbon adsorbents had a honeycomb-like turbostratic microstructure with hierarchical porosity and were produced from waste cellulose fibres using the spray-drying technique to extract methyl orange (MO) from water. Porous materials are classed by the diameter of the pores that make them up, accordance to the International Union of Pure and Applied Chemistry-USA (IUPAC), and the three divisions are shown in Fig. 3.

Because of its accessibility and abundance, biomass, a type of natural carbon raw resources, has been often used for the synthesis of porous carbon (Wang and Hu, 2018). Moving on, the waste cellulose fibre derived PC sample with the greatest specific surface area (about 1259.4 m^2/g) and total pore volume (about 2.7 cm^3/g) thermally treated at 800 °C showed an excellent MO adsorption capacity (337.8 mg/g), which is considerably greater than that of $ZnCl_2$-activated carbon, as well as the best reusability performance (Sun et al., 2019). The porous structure is formed by the inherent organised networks of biological tissue of plant characteristics (Wang and Hu, 2018). However, the adsorption capacity and regeneration potential of pure porous carbon materials are restricted. To address this, a popular modification approach known as metal doping is employed to increase porous carbon's adsorption effectiveness by altering its surface characteristics (Xiao et al., 2021). Surface modification and element doping are two more popular ways to change surface characteristics (Xu et al., 2017). One of the modification method that being displayed by Xu *et al.* (Xu et al., 2017) was the nitrogen-doping with 2 wt. % of hexamine that described as modification of porous carbon with nitrogen has improved the capacitance of electrodes for supercapacitor systems. Despite the fact that metal doping may greatly increase the adsorption and regeneration performance of porous carbon, the preparation process is quite difficult, and a simple and effective preparation technique must be developed as soon as practicable (Xiao et al., 2021).

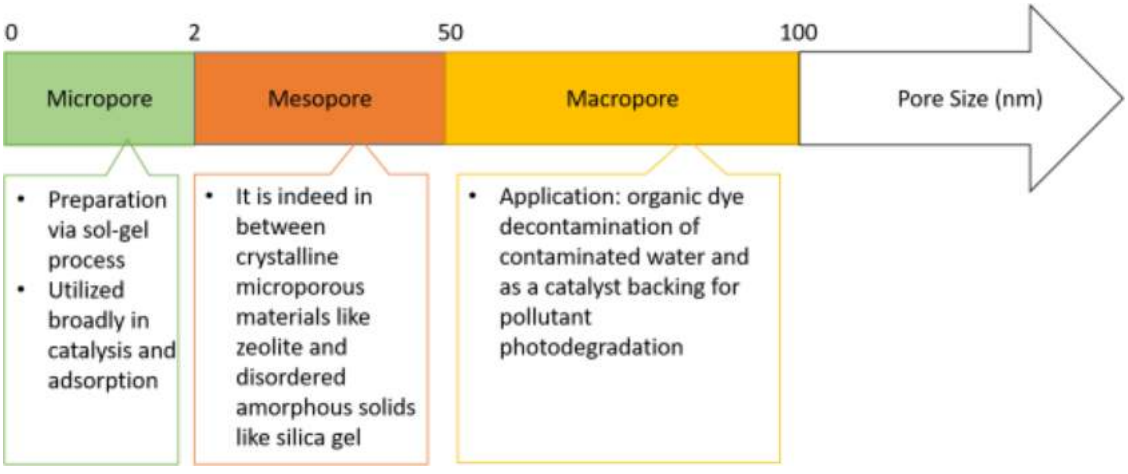

Fig. 3. Categorization of porosity depending on pore diameter based to the International Union of Pure and Applied Chemistry (IUPAC) (Ben Mosbah et al., 2020).

3.1. Activated carbon

Activated carbon (AC) is described as a carbonaceous solid with a large proportion of micropores, a great adsorptive potential and an enhanced surface area. As a result, AC has been categorized as an excellent adsorbent in the treatment of water and the regulation of air pollution. The appropriate use of AC is determined by its features, which vary depending on the raw precursor utilized and the production method used Ahmed, 2017. In pure context, AC composition is non-polar and correspondingly, ACs have a high adsorption capacity for several kinds of non or slightly polar organic compounds, especially phthalates, PAHs, PCBs, phenolic compounds, and pesticides (Björklund and Li, 2017). Activated carbon is commonly implemented in the treatment of drinking water and wastewater, but it has limited use for other types of contaminated water, such as storm water, which is frequently contaminated with nutrients, organic pollutants and metals, that can pose a risk to receiving waters, bio-accumulate in organisms, and have given rise to detrimental effect on human and animal health (Björklund and Li, 2017). The use of activated carbon (AC) in water treatment and purification is growing in popularity around the world (Jjagwe et al., 2021). Heavy metals, disinfection by-products, pesticides, natural organic matter, medicines, and microplastics are among the contaminants that have shown a higher removal effectiveness by AC (Jjagwe et al., 2021).

For decades, porous carbon materials, particularly activated carbons, have dominated as separation media due to their special physicochemical characteristics that can be fine-tuned (Borchardt et al., 2017). Pore structure and surface characteristics are two key factors that influence porous carbon materials adsorption in aqueous systems. Hence, controlling these carbon properties is critical for creating high-performance carbon adsorbents for the adsorptive total removal of bulky dye molecules (Sun et al., 2019). The majority of researchers preferred the adsorption approach because of its convenience, efficiency, and inexpensive. That several materials, like as porous carbon, are utilized as adsorbents because they have a large specific surface area, sizable porosity, a well-developed pore structure constituted of micropores, mesopores, and macropores, and a huge proportion of oxygen-containing functional groups, that are favourable adsorption conditions (Xiao et al., 2021). In catalytic Ozonation, carbon materials, especially activated carbon, are invariably used as heterogeneous catalysts (Gümüş and Akbal, 2017) (Mousavi, Dehghanzadeh and Ebrahimi, 2017). Due to the participation of activated carbon as both a catalyst and an adsorbent, the combined process outperforms Ozonation alone. Bello and Raman investigated the treatment of saline wastewater using a combination of Ozonation, photocatalysis, and activated carbon adsorption (Bello and Raman, 2019). The practicability of recovering wasted activated carbon through ozonation, and a partial regeneration of roughly 40% was obtained in the study (Bello and Raman, 2019).

The existing literature on AC is extensive and focuses particularly on two available types of AC; powdered activated carbons (PACs) and granular activated carbons (GACs). The PACs characterized as small particles settle and remove more slowly compare to GAC's and cannot be regenerated because difficulty in extracting it from the aqueous solution, as well as the risk of excessive dust pollution levels. However, the PACs have high adsorption capacity due to their large specific surface region and microporosity. (Jjagwe et al., 2021). GAC has disadvantaged adsorption capabilities as compared to PAC for pollutant removal from aqueous solutions where it contributed by the fouling result, as well as the restricted mass transfer of the contaminants (Cai et al., 2020; Jjagwe et al., 2021). GAC used in water treatment for 0–9 years was crushed into PAC, and its capacity to absorb 2-methyl isoborneol remained excellent, according to a research (Pan et al., 2017). The choice of GAC is based on the pollutant's targeting, concentration intensity, rate of flow, and adsorption potential. GAC is presently being utilized as a water treatment technology to successfully eliminate organic micropollutants, pharmaceuticals, arsenic, carcinogenic chemicals, microplastics, heavy metals, colour, and odour (Jjagwe et al., 2021).

3.1.1. Synthesis, activation and modification

ACs have recently been produced from agro-industrial wastes to reduce the cost of adsorption systems Ahmed, 2017. Commercial activated carbon for wastewater treatment are currently made from coconut shells, coals, woods, and lignite. Large surface area and porosity, as well as surface chemistry that reacts with molecules with particular functional groups, are all desirable features of ACs that allow them to be used in adsorption. Furthermore, since wastewater treatment is less lucrative than other industrial sectors, lowering the cost of treatment is always preferred. Since the last decade, the possibility of bio-waste to generate low-cost adsorbent has been discovered, and several research have been performed to evaluate the properties and performances of ACs made from various bio-waste in removing various contaminants from wastewater (Wong et al., 2018).

AC preparation is constituted of several fundamental steps: pretreatment, impregnation, activation washing and drying, and also sieving Ahmed (2017). Thermal and chemical activation are two types of activation methods to produce a porous structure from a low-surface-area material. After initial treatment and pelletizing, physical (thermal) activation involves carbonization at 400–500°C to remove volatile matter, followed by partial gasification with an oxidizing gas such as steam or flue gas (800–1000°C) and carbon dioxide, which is favoured due to its clean, convenient, flexible use, and uniform pores formation Ahmed (2017), directs the way to the production of surface area, functional groups, and porosity. On the other hand, the chemical activation employs the impregnation of additional ingredients such as NaOH, H_3PO_4, $ZnCl_2$, and K_2CO_3 oxidants Ahmed (2017), to the synthesis method prior carbonization (pyrolysis) (Sabzehmeidani et al., 2021). The carbonized precursor, also known as char, is made by pyrolytically decomposing the raw precursor at temperatures ranging from 400 to 850 °C. The char has a high surface area and porosity, which can be increased further by an activation process, resulting in a more porous product named as AC Ahmed (2017).

Among the activating agents, phosphoric acid (H_3PO_4) is often used to activate a variety of lignocellulosic materials. Because cellulose is resistant to acid hydrolysis, the acid interacts first with the cellulose and lignin in the phosphoric acid-lignocellulose interaction. Activation with phosphoric acid is used to make activated carbon from a variety of biomass sources (Heidarinejad et al., 2020). The study from Tuli et al. (2020) confirmed that the H_3PO_4-AC revealed superior adsorptive capabilities and features. H-AC has a greater surface area (850.58 m^2g^{-1} with many tiny pores on the surface, as well as a high methylene blue removal effectiveness (about 98%). As a result, phosphoric acid may be regarded as a more effective activating agent than potassium hydroxide (KOH) and zinc chloride ($ZnCl_2$) in tea waste-derived a AC. Tran et al. (2021) demonstrated that by employing hydrothermal and chemical activation with KOH, hydrothermal carbonised coffee husks were successfully to produce activated carbons via soaking techniques with a low potassium hydroxide concentration (ACHC-KOH 1 M). ACHC-KOH 1 M have highest adsorption capabilities (367.65 mg/g) toward MB, respectively. The hydrothermal carbonization approach yielded ACHC-KOH 1 M activated carbon comprised several benefits of MB adsorption in comparison to conventional procedures, including increased adsorption capacity, a way lower cost, and recoverable of unused KOH.

A considerable amount of literature has been published on the activation by $ZnCl_2$. The study from Whitaker et al. (2018) implemented through one-step chemical activation with $ZnCl_2$ to produce and evaluate activated carbon samples from sawdust species. The adsorbents' adsorption capabilities were examined using methylene blue in a monocomponent synthetic solution as well as heavy metals from contaminated river water. In the case of *Colicodendronscabrida* (CSs), the highest methylene blue (MB) adsorption was 250 mg/g, whereas for *Cedrelinga catenaeformis Ducke* (CCs), it was 357 mg/g. Both ACs had equivalent

capacities for absorbing As and Pb from real-polluted river water. Within the first 5 minutes, they achieved extremely high elimination levels of both heavy metals, nearly approaching 100% (Whitaker et al., 2018). Pyrolysis of hydrolyzed *Dipterocarpus alatus leaves* (HDL) treated with $ZnCl_2$ as an activating agent produced activated carbons obtained 338.86 mg as the maximal monolayer adsorption capacity of cationic dye (Khangwichian et al., 2022).The literature on $ZnCl_2$ activation on the olive solid waste-based AC has highlighted that it effectively adsorbs nitrate ions from water with high absorption capacity values, resulting the treated wastewater with only minimal nitrate levels within acceptable limits. The adsorption of nitrate onto $ZnCl_2$-AC is influenced by the pH of the solution. Overall, the findings reveal that $ZnCl_2$-AC has a high capacity for adsorption of nitrate ions, making it a potentially beneficial and safe alternative for nitrate removal from water (Nassar et al., 2020).

In term of modification, adsorption on activated carbons, particularly modified activated carbons, was applied to eliminate different contaminants such as dyes and pharmaceutical compounds, according to several studies (Sellaoui et al., 2017). The presence of polar surface functional groups can promote the hydrophilicity of ACs, and the surface chemistry can be altered to improve chemical selectivity of particular chemicals. Apart from that, inorganic like Cu, Pb, and Zn, as well as nitrate, nitrite, and ammonia, and also sulfides, chlorides, and cyanides, have been found to adsorb onto modified ACs (Björklund and Li, 2017). In a study done by Ahmed et al. (2019), by creating high-performance ultra-microporous ACs from biomass feedstock (slash pine wood; pyrolysis carbon) with good carbon dioxide adsorption capacity while reducing chemical usage by 70%, the results are remarkable. Fig. 4 shows the morphological structure differences of ACs made from slash spine wood and pyrolysis carbon (PC) using $ZnCl_2$ and KOH.

3.1.2. Limitations of activated carbon

This study has some potential limitations where a facile process used for the clean production of AC for CO_2 adsorption has been reported in laboratory scale experiments (Ahmed et al., 2019). In compared to other AC, the CO_2 sorption capacity employing AC developed in this study performed reasonably well. By creating high-performance ultra--microporous ACs with good carbon dioxide adsorption capacity while reducing chemical usage by 70%, the results are substantial (Ahmed et al., 2019). Nevertheless, long-term laboratory as well as pilot-scale studies should be conducted for actual application of this method in order to further assess the viability of the process and the performance of the produced AC. So yet, only a single pure gas has been used to assess performance (only CO_2 adsorption). As a result, it is indeed necessary to investigate the impact of other gases including nitrous oxide, carbon monoxide, and methane on CO_2 adsorption. Several adsorption and desorption cycles of ACs should also be completed to assure the reusability of the generated AC. In addition, a full cost estimation like the operation, maintenance, and production cost to demonstrate the economical of the process.

3.2. Graphene and graphene oxide

Graphene is another carbon-based adsorbent with outstanding structural, mechanical, electrical, and thermal characteristics. The material is made up of a two-dimensional hexagonal structure of carbon atoms (Bello and Raman, 2019). Graphene is composed of single-layer graphite and it has encouraging capacity in environmental remediation employment (Gopinath et al., 2021). Graphite is structurally anisotropic, which means that the characteristics of the in-plane and out-of-plane surfaces differ in properties values (Safian, Haron and Ibrahim, 2020). On the other hand, graphene is the fundamental unit of graphitic derivatives, consisting of a two-dimensional honeycomb lattice of atomically thin carbon layers with sp^2–bonded carbon atoms (Donga et al., 2021). Graphite is one type of carbon allotrope that has sparked a lot of attention because of its electrical, mechanical, and thermal characteristics (Jiang et al., 2019). For the adsorption of organic compounds, graphene is the best carbon-based adsorbent. Graphene performed better compared to other carbonic structures such as activated carbon (AC) and carbon nanotubes (CNTs) in terms of organic adsorption (Kumar et al., 2017). The graphene production is done by exfoliating the layers of graphite compound layer by layer until only a 'honeycomb' carbon sheet remains (Safian, Haron and Ibrahim, 2020). The honeycomb structure of graphene is shown in Fig. 5.

Graphene is a honeycomb-shaped sp^2 hybridised carbon structure

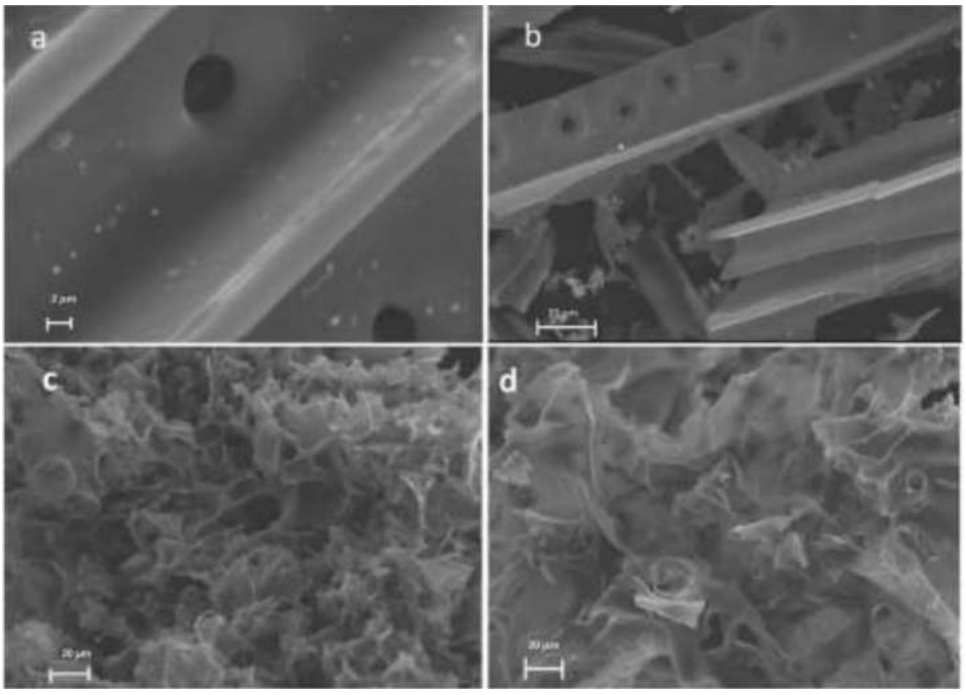

Fig. 4. AC materials as shown using a SEM (a) AC made from slash pine wood with $ZnCl_2$; (b) AC made from PC with $ZnCl_2$; (c) AC made from slash pine wood with KOH; (d) AC made from PC with KOH retrieved from (Ahmed et al., 2019).

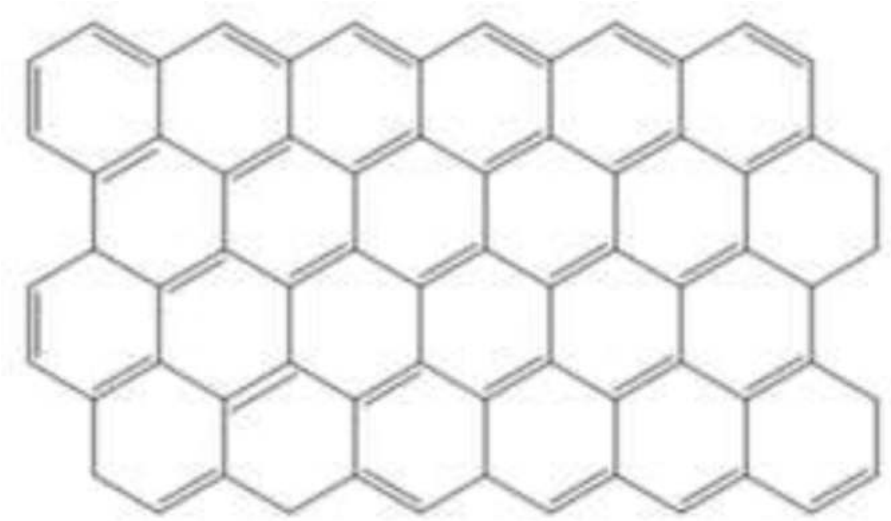

Fig. 5. Graphene honeycomb structure (Safian, Haron, and Ibrahim, 2020).

arranged on the same plane with bonding at a 120° angle, as illustrated in Fig. 5. Graphene has a high inherent mobility and ballistic transport since each carbon atom has an unhybridized -bond. Furthermore, the integration of σ—bonds and π-bonds contributes with the toughness of the structure along with the presence of radical ions comprehensively around the structure. As a result, graphene can endure high temperatures without losing its structural integrity (Safian, Haron and Ibrahim, 2020). The dense packing of carbon atoms in graphene sheets, and therefore the presence of electrons that may easily travel in the two-dimensional plane, are a benefit in graphene characteristics. They illustrate graphene's positive features, including its high thermal conductivity (5 000 W/mK), theoretical specific surface area (2 630 m^2/g), tensile strength (130 GPa), electrical conductivity (200 000 cm2/VS), and Young's Modulus (1 TPa) (Donga et al., 2021). Mechanical strength, as well as electrical and optical characteristics, are all uncommon features of graphene (Safian, Haron and Ibrahim, 2020). A single graphite layer or two graphite layers packed in a parallel configuration (Wilson, George and Jose, 2018). Graphene oxide (GO) is an oxidised form of graphene containing functional groups, whereas reduced graphene oxide (RGO) is synthesized by eliminating the oxidised functional groups of GO using the reduction approach (Safian, Haron and Ibrahim, 2020).

Graphene oxide (GO) and reduced graphene oxide (RGO) are in greater demand in many research fields which result in the synthesis of these materials on a large scale in a cost effective manner is becoming more concerned for numerous applications (De Silva, Huang and Yoshimura, 2018). Graphene oxide is an oxide-based compound made from a modified form of graphene. It is made of oxidising graphite and then exfoliating it, resulting in an imperfect but still usable lattice. The oxidation process usually involves acid reactions or combustion such as the Hummer's method which uses sulphuric acid, sodium nitrate, and potassium permanganate, the most widely acknowledged oxidation method. Nevertheless, other methods promising more thorough oxidation have also been developed. The exfoliation process is greatly improved by oxidation of the graphite, which is why GO is far less expensive than graphene. Graphene oxide, GO), have been regarded as attractive materials for the development of separation membranes because of their unique microstructures and properties (Jin, 2021).

The lesser cost and higher permeability because of the oxidation of the pristine graphene structure, has increase the interest among researchers to work on the fabrication of GO for water treatment purpose. GO membranes are made using a layer-by-layer method, in which thin sheets of GO are layered on top of one another using vacuum filtration or evaporation. Despite early research suggested that GO membrane proved impermeable to even helium, it has recently been discovered that water can pass through them with the appropriate development processes. The membrane thickness can be varied in the filtration-assisted process by adjusting the concentration and volume of the GO suspensions (Wei et al., 2018).

The reduction reaction can produce a reduced graphene (rGO), a material with partially repaired graphene lattice that enable the GO to increase in its strength and and electrical conductivity but not to the same extent as pristine (unoxidized) graphene. Due to its astonishing graphene-like properties and a variety of rather facile synthesis routes leading to decent amounts, RGO is proving itself to be a highly versatile material in many technological branches and it is finding use in more and more devices and applications (Tarcan et al., 2020). The functional groups are also changed during the reduction, which may affect surface interactions. Another intriguing feature of GO's reactive groups is that they allow the material to be blended with other materials (metallic inclusions, polymers) to generate novel combinations. For example, GO has been combined with silver nanoparticles to create materials that are antibacterial. GO can be mixed with other materials like poly(vinyl alcohol), chitin, or poly(vinylidene fluoride) to create membranes with different topologies, pore diameters, and reactivities.

GO dissolve well in water and other organic solvents due to the existence of oxygen and hydrogen-based functional groups in it, which making the production of GO-based membranes easier (Wilson, George and Jose, 2018). Despite the fact that RGO seems to be very identical to graphene, the extreme oxidation and reduction process causes defective spots in the RGO sheets. There are functional groups that have not been reacted while still bound to the RGO (Safian, Haron and Ibrahim, 2020). Fig. 6 demonstrate the comparison of structure between graphene oxide (GO) and reduced graphene oxide (RGO).

3.2.1. Synthesis and Modification

There are two types of graphene synthesis methods: top-down and bottom-up (Donga et al., 2021) as shown in Fig. 7.

According to Jabarullah, Kamal and Othman (2021), the Ancheson process is a widely used method for producing graphite. Amorphous carbon was heated to 3000°C in this thermal heating method. Since it takes around two weeks to process, the energy and time consumption is enormous, resulting in high manufacturing costs (Jabarullah, Kamal and Othman, 2021). The known synthetic techniques such as Brodie, Hummers, Modified Hummers, and Improved Oxidation are used to synthesis graphene derivatives such as GO and RGO from cost-effective graphite powder/flakes (Donga et al., 2021). These synthesis methods include the chemical oxidation of graphite employing a combination of strong acids

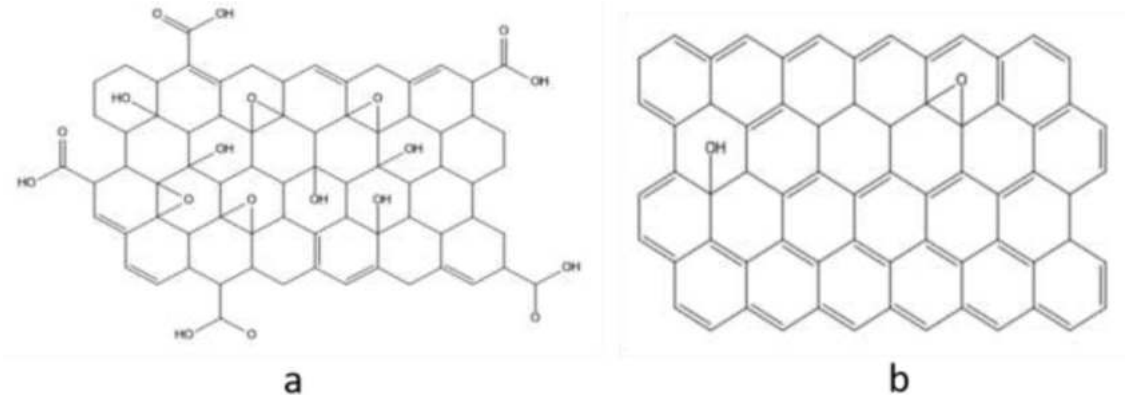

Fig. 6. (a) The graphene oxide (GO) structure and (b) The reduced graphene oxide (RGO) structure (Safian, Haron, and Ibrahim, 2020).

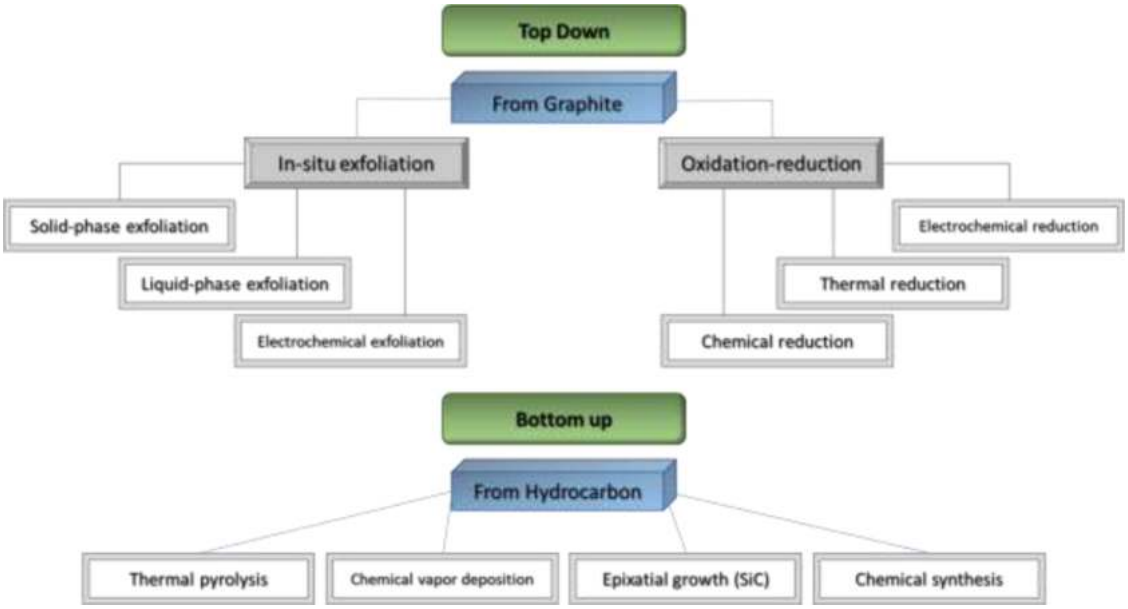

Fig. 7. Diagram of the top-down and bottom-up methods of graphene synthesis (Donga et al., 2021).

like H_2SO_4 and strong oxidising agents like $NaNO_3$, $KMnO_4$ that introduces different hydrophilic oxygen moieties to GO, like hydroxyl, carboxylic, ketone groups and epoxy (Donga et al., 2021). Previous study established the study of synthesis of GO from Indonesian environmental biomass (coconut shell, rice husk, bagasse) through modified Hummers method (Supriyanto et al., 2018). In this study, the employment the $KMnO_4$ as an oxidant and concentrated H_2SO_4 was used to exfoliate a number of layers from the graphite flakes (Supriyanto et al., 2018). In a further progress, graphite was also compose using other methods, including as solvothermal synthesis, chemical vapour deposition (CVD), laser ablation, and arc discharge (Thambiliyagodage et al., 2018). CVD was considered to have the most auspicious as a method for producing high-quality, large-area, and single-layer graphene. Due to its scalability and capability to generate high-quality graphene films, the graphene growth via the CVD method is still a dependable way to produce graphene (Sabzehmeidani et al., 2021). Despite that, these procedures need severe conditions such as increased temperatures, significant energy usage, and specialised and sophisticated instruments (Jabarullah, Kamal and Othman, 2021). Generally, carbon clusters of various sizes form on the irradiated graphite exterior by laser ablation. The graphite may be evaporated in the form of carbon nanoparticles and subsequently formed on the substrate surface to produce a restructured thin graphene layer by focusing the laser on the graphite surface and regulating the values of critical process parameters (i.e., laser energy, working pressure, ablation volume, background gas, target–substrate distance, and focal length) to the required quantities (Sabzehmeidani et al., 2021). There are relatively few approach in the area of graphene synthesis being reviewed by Arifin et al. (2020) based on Table 1 below.

Graphene oxide (GO) is produced by oxidising graphene using strong acids or oxidizers. GO is a reconstructed graphene with oxygen and hydrogen atoms linked to carbon atoms (Wilson, George and Jose, 2018). Catalytic graphitization is known as the process of converting amorphous carbon into a well-ordered graphitic structure via a heat action in the existence of metals or minerals (Jabarullah, Kamal and Othman, 2021). This corresponded with Thambiliyagodage et al. (2018) statement where the catalytic graphitization is defined as a heat treatment process involving a metal catalyst to develop the process. Fe, Ni, and Co have all been proven to be efficient catalysts in the synthesis of graphite, with iron being the most effective metal due to its magnetization, toxicity, and cost efficiency (Jabarullah, Kamal and Othman, 2021). A practicable technique, for example catalytic graphitization utilising lignocellulosic materials as a carbon precursor has become a viable alternative (Shi et al., 2019). Catalytic graphitization is a procedure with moderate process parameters, low temperature, and low energy usage. It makes use of solid feedstock, which would be a desirable choice owing to its simplicity of handling and transportation

Table 1
Graphene synthesis in the standard approach (Arifin et al., 2020).

Method	Benefits	Drawbacks
Chemical vapour deposition (CVD)	More simple approach for producing graphene with desired characteristics The type and thickness of the catalyst used determine the amount of graphene layers Graphene has a large surface area and excellent quality with few drawbacks	Not appropriate for large-scale manufacturing
Reduction of GO	The capacity to create it in large quantities and the ability to customize it. very suitable to be implemented out under mild conditions and less expensive	Might result in structural problems in the graphene created Common reductant used to reduce GO includes hydrazine, sodium borohydride (NaBH4) and hydrobromic acid (HBr) (hazardous reductant is used in most of the reduction processes that concerns the environment)
Scotch-tape method (mechanical exfoliation method)	Most typical conventional method High purity graphite will be divided into those few layers of graphene	Difficulty in breaking the van der Waals affinity between adjacent graphene flakes The formation of the monoatomic layer will be hard to manage. Not appropriate for large-scale manufacturing

(Jabarullah, Kamal and Othman, 2021). For instance, Fathy *et al.* have published a study on the production of graphene oxide from sugarcane bagasse. The authors developed a novel GO production technique based on a single-step reformation of sugarcane bagasse agricultural residues via oxidation with ferrocene at 300°C for 10 minutes in a muffled environment (Fathy, 2017). The study also reported in the literature that Fathy *et al.* applied a simultaneous activation-graphitization method of a coconut shell as a biomass waste using a graphitic catalyst precursor ($FeCl_3$) and an activating agent ($ZnCl_2$) at 900°C for 1 hour to produce porous graphene nanosheets with great surface areas (Fathy, 2017).

The functionalized graphene demonstrated favourable adsorption because of its high surface area (π-π interaction) and improved electrostatic interaction with adsorbates (Kumar et al., 2017). In general, graphene is naturally hydrophobic in high degree and has a high surface energy, which results in poor dispersion and intolerance with most organic solvents. Because of the strong van der Waals interactions, graphene disperses poorly in solution, causing in agglomeration of graphene sheets, limiting the potential uses of pristine graphene (Donga et al., 2021). As a response, surface modification utilising various polymers to provide functional groups on pristine graphene so as it required to minimise agglomeration and strengthen graphene compatibility (Kumar et al., 2017,Alaba et al., 2018). Those kind of hydrophilic groups are accountable for graphene oxide's exceptional properties and encourage its modification with a variety of organic and inorganic materials, contributing to elevated applications of GO in supercapacitors, batteries, fuel cells, water purification, photocatalytic, and antibacterial activities. The oxygen-containing groups in GO are removed by reducing it with chemicals like hydrazine and other powerful reducing agents by thermal and electrochemical methods, transforming it to RGO, which has a conjugated sp^2 hybridised structure (Donga et al., 2021). The incorporation of oxygen groups to graphene enhances its dispersion and raises the adsorption of anionic organic molecules. The amount of adsorption that can be performed on graphene is proportional to its accessible surface area. Graphene sheets have a high tendency to agglomerate, lessening the available surface area for adsorption considerably. The functionalization of graphene sheets with specific functional groups such as oxygen and sulfonate, from the other perspective, may minimise aggregation (Kumar et al., 2017).

In fact, the abundant functional groups in GO and organic compounds can interact with heavy metal ions via ion exchange, surface complexation, and chelation. Additionally, the high specific surface area can provide enough adsorption sites, enhancing the adsorption properties of GO/organic compound composites for heavy metal binding. For example, according to the study by Nizamuddin *et al* (Nizamuddin et al., 2019), Fe_3O_4 is a type of metal oxide that has been widely used in water treatment due to its huge specific surface area, biocompatibility, and exceptional magnetic properties. However, Fe_3O_4 tends to aggregate easily due to its small particle size and easily oxidization to form α/γ-Fe_2O_3. In compensating for this drawback, Fe_3O_4 was combined with GO to create magnetic graphene/iron oxide composites (Fe_3O_4/GO), which demonstrated the benefits of both Fe_3O_4 and GO nanoparticles in terms of sorption capacity and separation efficiency (Liu et al., 2019).

3.2.2. *Limitations of Graphene and Graphene oxide*

Electrochemical exfoliation is one of most efficient top-down graphene nanomaterial production methods among several methods (Prekodravac et al., 2021). Conversely, advances in graphene-based nanomaterial synthesis from biomass open up the possibility of discovering natural sources for the environmentally benign conversion of bio-waste to graphene, with a focus on the long-term sustainability and reusability of organic material in nature. So far, the natural sources and reaction conditions that have been investigated have led to a highly disordered graphene-based nanomaterials with a great specific capacitance and huge free surface area. The advantages of graphene synthesis from biomass pyrolysis include organic matter sustainability and reusability, eco-friendly bio-waste transformation, good specific capacitance and huge free surface area. However, biomass pyrolysis has limitations such as small-scale manufacturing, time-consuming processing of starting materials, and extremely disordered graphene.

3.3. *Carbon nanotubes*

The limitations of typical adsorbents have been directed in current development of nano-adsorbents due to its large surface area combined with a higher number of active sites, adjustable pore size, rapid kinetics, and better surface chemistry (Usman et al., 2018). The nanomaterials disclose characteristics such as electron affinity, mechanical strength, and flexibility, which can be utilized for water treatment and desalination during functionalization (Alam et al., 2020). Carbon nanotubes (CNTs) are nano-architectured allotropes of carbon , build from graphene sheets that are enclosed around one another to produce a cylindrical shape (Rahman et al., 2019). Omoriyekomwan *et al.* (Omoriyekomwan et al., 2021) stated that CNTs are 1-D carbon nanomaterials composed of graphitic tubular structures with a diameter in the nanometer scale and a length of several centimeters. In other words, carbon nanotubes are tubular carbons with high surface areas, a porous structure, and a strong susceptibility to contaminants (Bello and Raman, 2019). Several researches have shown that multi-walled carbon nanotubes are effective at removing metal ions such as chromium (III) (Manilo, Choma and Barany, 2017). The material can be adjusted due to their tuneable form (Gopinath et al., 2021).

These carbon materials could be divided into two groups based on their texture: nano-textured and nano-sized carbons (Yadav et al., 2021). Carbon fibres, pyrolytic carbons, or glass-like carbons, and diamond-like carbon compounds all fall under the category of nano-textured carbons. Fullerenes, graphene, and carbon nanotubes are examples of nanosized carbons (or nanocarbons) (Rahman et al., 2019). CNTs are produced by rolling a sheet of graphene into a cylindrical shape, which may have a capped or open end, and are generally hexagonal in shape and close packed with a diameter of 1 nm as well as a

length of a few microns (Aslam et al., 2021). Another kind of carbon nanotube is the double-walled carbon nanotube (DWCNT). MWCNTs are made up of many layers of graphite folded itself around such a rolled-up newspaper, resemble a Russian doll, placed in side-by-side cylinders or a single sheet of graphite (Fathy, 2017). In brief, single-walled carbon nanotubes (SWCNTs) and Multi-walled carbon nanotubes (MWCNTs) are the two varieties of CNTs based on the number of layers. The comparison of the properties between SWCNTs and MWCNTs are shown in Table 2.

Some of the disadvantages using raw CNTs is their low dispersion in solutions and low adsorption capacity with organic and inorganic composites. The main cause of the original CNT samples' low contaminant adsorption efficiency is aggregation (Ali et al., 2019). Functionalization of CNTs involving oxidation treatment has been commonly adopted to improve the dispersity of CNTs, as well as their adsorption capacities for aquatic contaminants. However, chemical oxidation of CNTs requires harsh chemical conditions and results in the generation of chemical waste. In this regard, innovative techniques are warranted for the functionalization of CNTs with no or minimal structural damages and environmental pollutions. CNT materials are still more expensive than other materials including carbon black, carbon fibre, clay, and exfoliated graphite, which limits their application as adsorbents in full-scale water treatment (Ali et al., 2019).

3.3.1. Synthesis and modification

The production of renewable carbon sources for the synthesis of CNTs may come from biomass conversion which generated from lignocellulosic biomass. It has been demonstrated to be a viable bio-feed. It includes a considerable quantity of cellulose, which has been shown to be the precursor for CNT formation in several experiments (Omoriyekomwan et al., 2021). According to the literature, converting lignocellulosic biomass by pyrolysis at high temperatures (700–900°C) and high pressures (2–4 MPa) might result in the generation of high molecular polycyclic aromatic hydrocarbons (PAHs), which can be used as a carbon source for CNT production (Matamba et al., 2020). CNTs generated from biomass have a large specific surface area, minerals, and a variety of functional groups, making them effective adsorbents. They may also be employed as possible filler materials in polymer composites improving the toughness, stiffness, and electrical conductivity of polymers (Omoriyekomwan et al., 2021).

Various approaches can be used to manufacture CNTs with the desired characteristics needed for a specific application. In general, those techniques that generate CNTs with fewer structural and chemical defects are favoured. Different techniques for the synthesis of CNTs are briefly discussed in this section. CNTs may be made in large quantities utilising a variety of techniques that are usually divided into five categories: electrolysis, carbon arc discharge, laser ablation, sonochemical or hydrothermal processes, and chemical vapour deposition (CVD) are some of the techniques used (Sabzehmeidani et al., 2021). In this review, the carbon arc-discharge process, laser ablation, and chemical vapour deposition (CVD) are discussed as the primary methods for producing CNTs. In all synthesis techniques, carbon nanotubes are created by employing energy and carbon sources (Aslam et al., 2021).

Table 2
Properties comparison of SWCNTs and MWCNTs.

Properties	SWCNTs	MWCNTs	Refs.
Layer type	Single graphene layer	Multiple graphene layers	(Rahman et al., 2019)
Catalyst requirement	Require catalyst	No need catalyst	(Aslam et al., 2021)
Purity level	Poor	High	(Aslam et al., 2021)
Specific gravity	About 0.8 g/cm^3	Less than 1.8 g/cm^3	(Rahman et al., 2019)
Diameters	between 0.3 and 3 nm	up to 100 nm	(Arora and Attri, 2020)

Arc discharge require high temperature for carbon atoms to vaporise into plasma. An electric arc can be produced between two closely spaced graphite electrodes when the pressure is around 50 and 700 mbar in an inert gas atmosphere environment. The temperature must be higher than 3000°C to create carbon plasma (Chen, Wei and Xie, 1948). The earliest technique of generating CNTs is by arc discharge between graphite electrodes. In this approach, a graphite electrode pair is exposed to a direct current of 50 to 100 A and a potential difference of about 20 v in the presence of helium or argon at a pressure of 500 Torr. The high temperature created by the discharge of electric current in low pressure, inert gas, and catalyst caused the carbon electrode surface evaporates and develops a cylindrical-shaped tube structure. MWCNTs could be made using an arc discharge technique without the need of a metallic catalyst; however, SWCNTs production require the use of mixed-metal catalysts such as iron, cobalt, and nickel (Aslam et al., 2021). The SWCNT and MWCNT synthesis techniques such as arc discharges and laser ablation are depending on the condensation of hot gaseous carbon atoms produced by the evaporation of solid carbon. The arc-discharge method grows SWCNTs with the help of a metal catalyst. The laser ablation technique may also generate around 1–10g of fine-quality SWCNTs. However, the high energy demand and expensive instrument requirements restrict this technique, thus making it less suitable for the manufacturing of nanotubes. The primary drawbacks of arc discharge are the purification requirements, as well as tangled nanotubes (Sabzehmeidani et al., 2021).

Laser ablation works on the same concept as arc discharge, instead the method utilises a laser to heat the carbon target. The carbon target is then vaporised before condensing in a carrier gas stream. The impact of laser wavelength was investigated in the production of single-wall carbon nanotubes (SWCNTs) and their characteristics (Chen, Wei and Xie, 1948). In a nutshell, a high-energy laser beam is used to target a graphite object at 800–1200°C temperature and 500 Torr pressure in the presence of argon. A laser pulse acts as an energy source, while a graphite object serves as a carbon supply in this approach. The uniform evaporation of the target caused by the continuous application of laser pulses can prevent carbon soot build up. Following the initial laser beam, the bigger particles are broken down into smaller ones by subsequent laser beams. The smaller particles are then incorporated into the CNT framework. Frequently, transition metals are employed as catalysts in this approach. Laser ablation can be used to find rope-shaped CNTs with a diameter of 10 to 20 nm and a length of around 100 mm (Aslam et al., 2021). Owing to the vaporisation propensity of the metallic atoms from the end of the tube when it is enclosed, the major benefits of this technique are reasonably low metallic impurities and a relatively high yield. The main disadvantage of this method is that the nanotubes produced may not be completely straight and may have some branching. Moreover, this process uses high-purity graphite rods and high-power lasers, and the number of CNTs generated is less than with the arc-discharge technique (Rahman et al., 2019). The technique also restricted to the lab-scale and require additional purifying of the crude product (Sabzehmeidani et al., 2021).

According to Sabzehmeidani et al. (2021), there are many examples of CVD, such as catalytic chemical vapour deposition (CCVD), thermal or plasma enhanced (PE) oxygen aided CVD, water assisted CVD, microwave plasma (MPECVD), radiofrequency CVD (RF-CVD), or hot-filament (HFCVD). CNTs are often produced using catalytic chemical vapour deposition (CCVD), which is the most common technique. CVD synthesized CNTs are not as excellent as arc charge or laser ablation synthesized, and catalysts such as cobalt, nickel, copper, and iron are invariably employed to split gaseous hydrocarbons into carbon and hydrogen by reducing the temperature (Chen, Wei and Xie, 1948). In contrast, however, the CVD technique has some advantages over the arc discharge and laser ablation processes, including (a) the ambient pressure and lower synthesis temperatures ability, (b) the ability to grow the crystallinity of SWCNTs at temperatures more than 900°C, (iii) the ease

capacity to monitor the morphology, (iv) the ability to decompose a wide range of hydrocarbons in any state (solid, liquid, or gas) (v) CNTs may be grown as powder, (thick/thin) films, (entangled/aligned) nanotubes, (coiled/straight) nanotubes, or bamboo nanotubes (Fathy, 2017). The sort of carbonaceous feedstocks, catalysts, substrates, and the required power consumption during the CVD process all play a role in CNT synthesis (Fathy, 2017).

In this case, the catalyst is inserted in a quartz or ceramic boat that is placed inside a quartz tube. An inert hydrocarbon and a hydrocarbon source make up the reaction mixture. At temperatures ranging from 500 to 1100 °C, this mixture is fed through a catalyst bed. After then, the system's temperature is lowered to room temperature (Rahman et al., 2019). The dissociation of hydrocarbon materials facilitated by the transition metal, as well as the saturation of carbon atoms in the metal nanoparticle, are both involved in the design of nanotubes in the CVD process. The existence of metal particles causes tubular carbon solids to form in a sp2 hybrid structure. The characteristics of CNTs synthesised by the CVD method are influenced by operational parameters such as pressure and temperature, hydrocarbon type, volume, and concentration, size and character and size of catalyst, reaction period and the support nature (Sabzehmeidani et al., 2021). To be illustrated, a CNTs synthesis study on carbonization of rice straw treated hydrothermally in the involvement of small quantities of catalyst sources, such as mono-catalyst of ferrocene or mixed catalyst of ferrocene with nickel nitrate salt (RS-H/Fe or RS-H/Fe–Ni) by CVD of camphor under flowing N_2 gas (Fathy, 2017). In this comprehensive study, CNTs with smaller outer diameters and coiled bundles were created using a bottom growth process over carbonized RS-H/Fe. Whilst, as shown in transmission electron microscope (TEM) imaging, a significant number of straight and big outer diameter CNTs-bundles were generated over carbonized RS-H/Fe–Ni through a bottom growth process. The varied growth patterns should be caused by the strength of the binding force between the Fe or Fe–Ni catalyst and the carbonized rice straw support. Since the binding force is strong, it will have a high chance of forming a base/bottom-growth mode with the catalyst particles deposited in the porous support nature microstructures (Fathy, 2017). Fig. 8 shows a novel laser-assisted approach for the synthesis of SnO2/MWCNTs nanocomposite has been devised for the treatment of water from Cu(II). A unique multi-walled carbon nanotubes/SnO_2 nanocomposite was formed using a sonication process and pulsed laser ablation in liquid media.

For modification approach, CNT-based technology may be combined with standard water treatment procedures by creating new cost-effective and efficient production techniques. Several research on CNT assisted catalysts have been done, with the goal of improving catalytic activity by utilizing common contaminants like dyes or phenol. CNTs provide a number of benefits over standard water treatment methods. They work as an efficient adsorbent with higher adsorption capacity, easier regeneration, and shorter equilibrium times, and higher adsorption selectivity. CNTs are a good catalytic support material. For instance, combining CNT with TiO_2 may increase visible photoactivity and greater charge separation (Arora and Attri, 2020). A large surface area undesirably cause agglomerations. Surface functionalization aids in scattering stabilization by inhibiting nanotube re-aggregation and encouraging the binding of polymeric grids with MWCNTs. Covalent functionalization of MWCNTs may be evaluated by identifying certain functional groups on MWCNT sites using oxidizing agents such as strong acids, which results in the production of hydroxyl or carboxylic groups (–OH, –COOH) on the exterior of the nanotubes. Functionalization-type defect groups are such of groupings (Abualnaja et al., 2021).

The π-π interactions and van der Waals force between CNTs cause reduced dispersion, resulting in tightly packed bundles and CNT aggregation (Aslam et al., 2021). The tendency to bunch rises when the number of graphite layers of CNTs reduces from MWCNTs to SWCNTs (Bounos et al., 2017). Hence, to address these constraints, CNTs' chemical reactivity and contaminant adsorption capacity must be increased by raising their dispersion rate, which may be accomplished by functionalizing the nanotube (Ali et al., 2019) (Oyetade et al., 2017). CNTs are typically functionalized to improve their dispersibility and pollutant removal effectiveness, allowing them to be used in water or wastewater treatment applications or encouraging membrane construction. To introduce oxidized functional groups, raw CNTs have been oxidized with HNO_3, H_2SO_4, HCl, H_2O_2, $KMnO_4$, and NaOCl, or occasionally a mixture of several of these. In general, oxidation enhances the dispersibility of water and wastewater, as well as the capacity to adsorb some hazardous pollutants (Aslam et al., 2021). CNTs may be managed to change with the addition of metal oxides such as Al_2O_3, MnO_2, and Fe_3O_4, which provide another means to coat the surface of CNTs, therefore enhancing the pollutant removal efficiency of CNTs, in addition to oxidation and plasma action for surface modification (Ali et al., 2019).

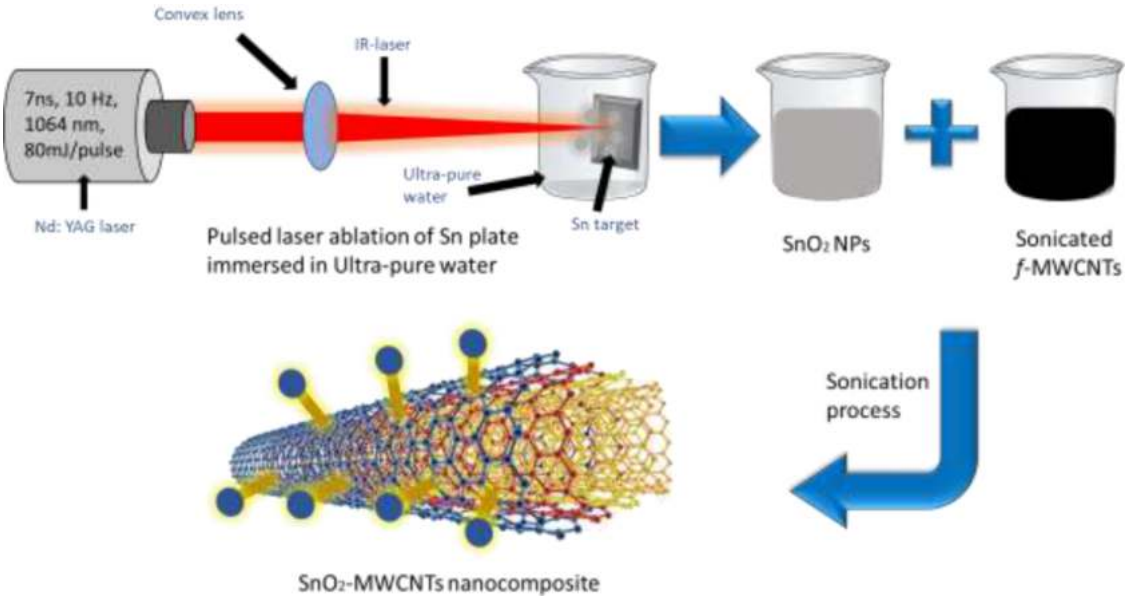

Fig. 8. Example of a modified CNT. A schematic diagram of synthesis SnO_2- MWCNTs nanocomposite retrieved from (Mwafy et al., 2021).

3.3.2. Limitation of carbon nanotubes

Chemical vapour deposition (CVD), catalytic chemical vapour deposition (CCVD), plasma-enhanced chemical vapour deposition (PECVD), arc-discharge and laser ablation successfully synthesise carbon nanotubes (Omoriyekomwan et al., 2022). However, these methods require a metal catalyst (Ni, Mo, Fe, Co), a substrate, and hydrocarbons (methane, ethane, acetylene, xylene) as carbon sources (Omoriyekomwan et al., 2022). The catalyst deactivation during CNT synthesis limits their growth and, as a result, hinders their practical application, which is a limitation of these studies. This can be addressed by inventing a new method for synthesising long CNTs with improved characteristics so that their maximum capabilities for industrial applications can be realized. The morphology and structure of carbon nanotubes upon microwave treatment can be utilized to regulate the quality and structure of CNTs made from cellulosic biomass.

3.4. Biochar

Carbon may be generated in three different ways from organic matter: biochar (BC), charcoal, and AC. They have many similarities, such as compositions and production methods, yet they differ in terms of practical uses. Charcoal is generally made from wood and being used as a fuel, whilst BC is thought to have soil conditioning and water treatment qualities, whereas AC is thought to have filter purification properties (Grünewald and Rullander, 2020). BC is a carbonaceous solid residue generated by pyrolysis at different temperature under oxygen-limited situations from a range of agricultural and industrial biomass resources (Kwak, 2019; Pan et al., 2017,). Toxic metals, organic contaminants, and nutrients have all been removed from wastewater using biochar as an adsorbent (Xiang et al., 2020). Biochar's ability to remove organic and inorganic pollutants is determined by its surface functional groups, surface area, pore size dispersion, and the size of the molecules to be removed, while its physical architecture and surface properties are determined by the nature of the feedstock and the procedure/conditions of preparation (Enaime et al., 2020). Organic pollutants can be eliminated via a variety of processes, including physical adsorption, π–π interaction, electrostatic interaction, and Fenton process, as well as photocatalytic degradation, relying on the sort of biochar-based material (Huang et al., 2019). Biochar is a porous carbonaceous substance created when biomass feedstock is thermochemically decomposed in the absence of oxygen. Any organic waste products, such as agricultural and forest residues, manures, algae, sewage sludge, wood chip, and organic municipal solid wastes, can be used as biomass feedstock (Xiong et al., 2019). Biochar has gained a lot of interest because of two unique advantages. First, biochar production can offset greenhouse gas emissions because it stores carbon in a stable form, thus reducing greenhouse gas emissions from biomass degradation into the environment. Second, due to its wide surface area and abundance of surface functional groups, biochar is an effective, low-cost, and environmentally compatible adsorbent (Xiang et al., 2020). Biochar and its activated derivatives have been reported as very effective materials for removing pathogenic organisms, inorganics such as heavy metals, and organic contaminants such as dyes, due to its remarkable properties such as rich carbon content, increased surface area, high cation/anion exchange potential, and stable structure (Enaime et al., 2020).

The unique capacity of biochar to eliminate organic and inorganic pollutants is highly related to the nature of the feedstock and the preparation method (Clemente et al., 2017). BC is a pyrogenic carbon-rich substance. This type of carbon material has a lot of desired qualities, for example high specific surface area, high ion exchange capacity, high porosity, and high amount of oxygen functional groups contributing to its excellent ability in wastewater treatment. Meanwhile, the material is made from a variety of biomasses, including crop straw, urban waste, and industrial waste. Compared to other materials, BC feedstock is widespread and inexpensive (Huang et al., 2019). The specific reason for biomass conversion is to transform solid carbonaceous material (Suman and Gautam, 2018).The quality of the biochar generated is determined by the physiochemical parameters of the biomass. The reactors in the various products all function on the same concept. However, the other factors for reactor operation (amount of oxygen utilised, heating time, and end temperature) differ, affecting the quantity and quality of biochar generated (Wang et al., 2020). Pyrolysis, gasification and torrefaction, and hydrothermal carbonization are the four basic methods used in biochar manufacturing (Gupta et al., 2022). The process of making biochar is shown in Fig. 9.

The efficacy of a commercial BC was evaluated on the removal of tetrakis(hydroxymethyl) phosphonium chloride (THPC, a water-soluble organophosphorus salt) (Akech, Harrison and Saha, 2018). Pursuant to the result, the adsorption capacity of BC toward THPC was found to be as high as 204 mg/g under optimal condition, indicating that the material has a lot of potential and may be used in a variety of wastewater treatment applications (Huang et al., 2019). Additionally, BC is able to be manufactured at lower temperatures than AC and require lower activation step in comparison with the AC (Fan et al., 2017). BC, in particular, as a low-cost adsorbent, can be applied to replace AC, which is utilized as a typical adsorbent because of its capacity to absorb a variety of contaminants (Wang et al., 2019).

Biochar-based technology is attracting the attention of an increasing number of researchers in the field of wastewater treatment due to the expeditious demand for reduced costs, increased performance, and a simple approach (Huang et al., 2019). Biochar have huge specific surface area, excellent ion exchange capacity, high porosity as well as the abundant oxygen functional groups which the great potential in wastewater treatment. However, based on the previous study, the adsorption capacity of pristine BCs is insufficient to meet practical demands to some extent, presumably due to their limited functions such as the poor hydrophilic property, limited surface area and active sites (Huang et al., 2019). In this aspect, biochar-based hybrid materials gradually receive great attention. These types of hybrid materials provide opportunities to satisfy the demand of low-cost adsorbents with better removal efficiencies by combining the advantages of foreign materials with BCs.

3.4.1. Synthesis and modification

Hydrothermal carbonization (HTC), gasification, torrefaction, and pyrolysis, are the examples of methods for converting organic wastes into char (Enaime et al., 2020). Biochar, an environmentally beneficial and low-cost substance made from organic wastes including agricultural wastes, forestry residues, and municipal wastes, is gaining popularity, as demonstrated by its growing usage in a variety of environmental applications (Sabzehmeidani et al., 2021). Pyrolysis is the most common technique for creating biochar, but chars from gasification, torrefaction, and HTC do not commonly fulfil the description of biochar given in the European Biochar Certificate standards (EBC) (Enaime et al., 2020). The manufacturing of BC is uncomplicated, using minimal energy (800°C), and the conversion of diverse waste materials into useful BC is also aids in reducing surrounding environmental stress (Huang et al., 2019). The characteristics of BC are generally determined by the type of materials used and the pyrolysis settings, such as pyrolysis duration and temperature, pyrolysis furnace, and heating rate (Arora and Attri, 2020). BC is synthesized by pyrolysis (300–700°C) of various biomass feedstock types under O_2-free or O_2-limited environments (Kwak, 2019; Mandal et al., 2017). Different kinds of biomass have different chemical compositions and structures, resulting in pyrolysis products with various structures and characteristics. In this paper, we briefly discuss some BCs produced from various types of biomass feedstocks from recent investigations, as well as a description of their properties. These biomass feedstocks could be divided into the following groups based on their source: (i) industrial by-products and municipal wastes, (ii) alternative materials (iii) agricultural and forest wastes (Huang et al., 2019).

In contrast to pristine BC, designed biochar has a greater surface area, a higher adsorption capacity, and more numerous surface

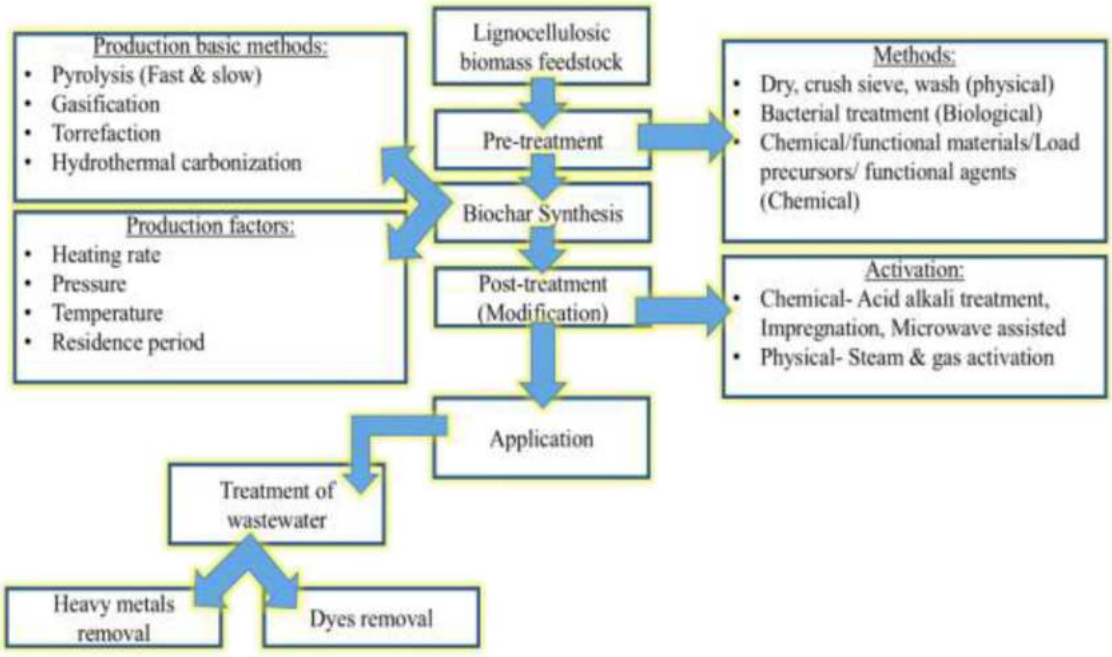

Fig. 9. Process of making biochar in a brief adapted from (Gupta et al., 2022) literature.

functional groups (SFG), making it a new form of carbon material with a wide range of applications in wastewater treatment (Xiang et al., 2020). A several types of biochar-based hybrid materials, such as nano-metal/nanometallic oxides/hydroxide BC composites, layered nanomaterial-coated BCs, and magnetic BC composites (MBC), while also physically/chemically activated BCs, have been developed in response to the need for more cost-effective materials. These hybrid BCs have remarkable capabilities to extract a wide range of organic pollutants from aquatic solutions, including organic dyestuff, phenols and chemical intermediates, as well as pharmaceutically active chemicals, with the aid of foreign materials (Huang et al., 2019). Chitosan and pyromellitic dianhydride, for example, were used to alter the surface of BCs, leading in much more surface functional groups and a high selective adsorption toward copper(II) ions (Deng et al., 2017). The characteristics of biochar should be adjusted to allow for improved removal effectiveness of some difficult degraded organic and inorganic compounds that are existing at low concentrations. The typical methods applied for biochar modification are consist of two classes; (i) chemical modification procedures, which primarily comprise acid modification, alkalinity modification, and oxidising agent modification (ii) physical modification methods, which mostly carry out by gas purging (Enaime et al., 2020).

Due to the low amount of functional groups and limited surface area and pore volume in biochar, as well as the fact that the pores formed during carbonization are plugged with tarred material in the case of dry pyrolysis, a successive chemical or physical treatment is needed to optimize the biochar's specific surface area, pore volume, and pore structure for its subsequent use in diverse environmental implementation (Enaime et al., 2020). The widely used modification techniques can be mainly divided into four groups, namely surface reduction, nanoscale-metals assistance, surface oxidation, and impregnation with mineral elements (Wang et al., 2019). Biochar is conducted to a controlled gasification at elevated temperature and in an activation environment during physical modification. After physical activation, significant changes in textural parameters such as pores distribution, surface area, and pores volume, as well as surface chemical properties which including hydrophobicity, polarity, and surface functional groups, were noted. Water steam is the most common oxidizing agent utilized in the physical technique of biochar modification (Enaime et al., 2020). During steam activation, chemical processes can selectively remove highly reactive carbon atoms from the original biochar, producing in porosity and surface area. The interaction of steam with carbon causes the removal of volatile chemicals and the breakdown of tar, resulting in the formation of new micropores and the expansion of existing pores (Enaime et al., 2020). Depending on the types and quantity of the acid, acid modification can alter the surface area and pore structure of biochar (Zhou et al., 2017).

The properties of biochar modified using alkaline agents are highly dependent on the source and the preparation process (Enaime et al., 2020). The ratio of base to biochar has also been identified as a key element influencing biochar characteristics (Shen and Zhang, 2019). As reported by Enaime et al. (2020), the use of organic solvents to modify biochar was also employed whilst methanol was used to modify a municipal solid waste-derived biochar and resulting in an esterification between the carbonyl groups and the biochar, causing in a substantial increase in tetracycline adsorption capacity. However, the use of organic solvent is limited by its large prices and volatile nature (Enaime et al., 2020). Due to the promising potential of biochar for pollutants removal, to enhance environmental quality, modifications of biochar by expanding specific surface area (SSA), reaction activity, or generating functional groups are becoming progressively crucial. According to the modifications, designed biochar as an adsorbent to eliminate aqueous pollutants such as heavy metals, organic contaminants, nitrogen, and phosphorus is regulated by different processes, namely ion exchange, adsorption, surface precipitation, surface complexation, and so on (Xiang et al., 2020).

3.4.2. *Limitation of biochar*

Biochar has several benefits, but there are certain limits based on the most of the literature findings. The biochars formed from plant materials as feedstock has been speculated that the volume of salts in the biomass are concentrated in the biochar, influencing the volume of salts leached into the water (Hong et al., 2019). Although biochar offers tremendous potential in treating of heavy metal-polluted water and has environmental and economic advantages over other adsorbents, its high production costs prevent it from being used on a big scale (Qiu et al., 2021). Hence the cheap raw material sand an efficient method for modification is necessary for the for a large-scale production of the biochar that have

the important characteristics such as improved surface area, surface charge, surface-active functional groups for the effective adsorption capabilities. In conclusion, making biochar feasible for the treatment of heavy metal-polluted water is crucial and requires effort (Qiu et al., 2021).

3.5. Carbon aerogel

Aerogels are solid materials that are filled with gas phase and are linked by colloidal particles to form a network structure. In other words, an aerogel may also be defined as a gel that characterized with a microporous solid which distributed in a gas phase (Sabzehmeidani et al., 2021). Aerogels are remarkably porous light materials with a number of excellent and special physical characteristics that have grabbed the interest of scientists and engineers working in a variety of fields. The majority of their distinctive features enable aerogel fine-tuning, hence resulting in highly tailorable end products (Zubair et al., 2019). So far, aerogels were classified as oxide aerogels, carbide aerogels, organic aerogels, and carbon aerogels depending on their matrix type (CAs) (Hu et al., 2019). Aerogels are categorized as microporous, mesoporous, or mixed porous based on their appearance as monoliths, powders, or films in various forms of structure. The most common categories are based on their composition, which specifies three types of aerogels: inorganic, organic, or inorganic-organic hybrids aerogels (Zubair et al., 2019). CAs were anticipated to be very promising materials for adsorbents, catalyst supports, electrochemical capacitors, and insulating materials (Sabzehmeidani et al., 2021). CNT aerogels, carbon micro-belt aerogels, graphene aerogels, and carbon fibre aerogels are examples of carbon-based three-dimensional (3D) frameworks (Xu et al., 2018,Sabzehmeidani et al., 2021).

Carbon aerogels are an interesting three-dimensional (3D) monolithic porous material with exceptional physicochemical characteristics, such as low density, high surface area abundant pore structure, adjustable surface chemistry, large electrical conductivity, environmental compatibility, chemical stability, and controllable structural properties. The characteristics contributed to the high adsorption and catalytic capabilities of the material. (Gan et al., 2019). The good adsorption and catalytic performance also due to the microscopic characteristics of carbon nanomaterials and the macroscopic framework of the gel. Furthermore, owing to their macrostructure, super elasticity, and high-temperature resistance, the material is able to be recycled (Gan et al., 2019). Consequently, carbon aerogel are frequently used in environmental chemistry to remove pollutants such as hazardous organic solvents, dyes, heavy metal ions, oils, and volatile organic compounds (VOCs), nitrogen oxide (NOx), hydrogen sulphide (H_2S), and carbon dioxide (CO_2, CO), from the atmosphere (Gan et al., 2019) CAs are quite simple to establish and manage. CAs were most often employed in previous research for oil/water and oil/organic solvent separations (Li et al., 2017). In a study by Aylaz *et al.* (Aylaz et al., 2020), the adsorption of crude oils, such as cooking, olive, or pump oils, on organic solvents including benzene, chloroform, methanol, acetone, ethanol, cyclohexane, n-hexane, and others was investigated. The adsorption of all these to CAs, resulting in extremely high adsorption capacities. However, these high capacities of CAs adsorption decline significantly to mg/g levels when the adsorption are done on antibiotics substances (Aylaz et al., 2020). Fig. 10 shows SEM images of carbon aerogel with enhanced thermal insulation and mechanical properties. Boron-modified phenolic resin (BPR) and hexamethylene-tetramine (HMTA) were crosslinked to create a three-dimensional network structure, which was then dried and carbonised using CO_2. Carbon aerogels made from biomass have received a great deal of interest in recent years since renewable biomass is biodegradable and ecologically benign (Danish and Wang, 2019,kang Gao et al., 2019). Interestingly, cellulose, chitosan, lignin, tannin, and biomass waste are new precursors utilised to make biomass-based carbon aerogels as illustrated in Table 3 below.

Turning now to another carbon gel which is the carbon xerogel. Basically, in order to produce xerogel, the gel is dried properly at ambient pressure and temperature. Organic xerogels are transformed to carbon xerogels (CXs) by pyrolysis, a process in which carbon scaffold is created by the removal of heteroatoms and functional groups at high temperatures in an inert environment. CX is denser and has a smaller overall pore volume than the comparable carbon aerogel (Peikolainen et al., 2021). Carbon-supported xerogels are easier and faster to make than aerogels and cryogels. Although, aerogels have higher adsorption

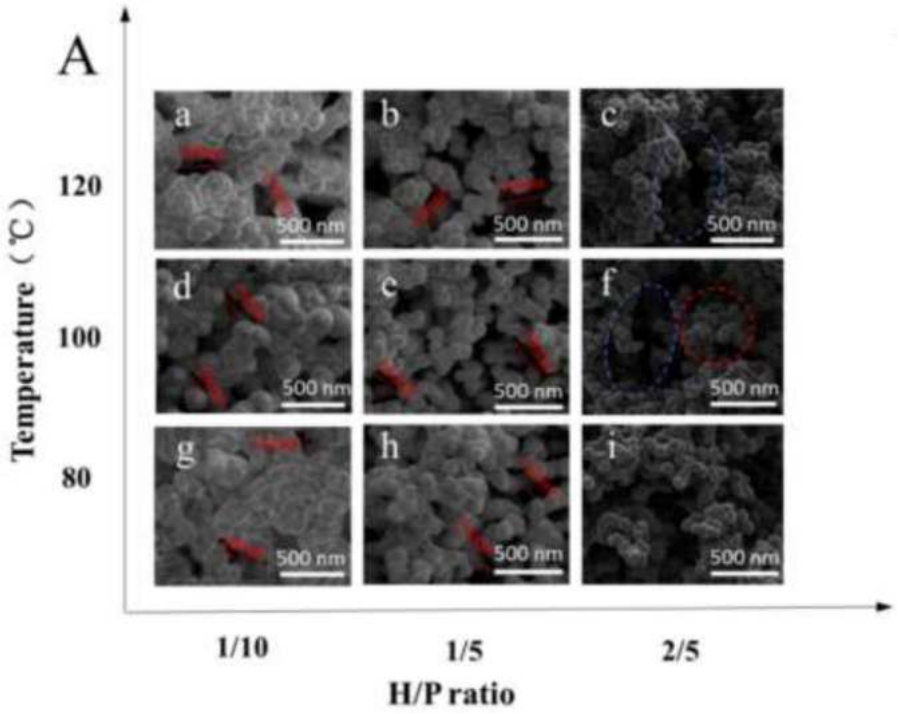

Fig. 10. SEM images of carbon aerogel with enhanced thermal insulation and mechanical properties retrieved from (Liu et al., 2021).

Table 3
A brief overview of the many forms of biomass for carbon aerogel synthesis (Sam et al., 2020).

Biomass waste	Proportion	Properties
Cellulose (wood, plant fiber)	A polysaccharide composed of lengthy chains of at approximately 500 glucose molecules joined together by hydrogen bonds.	Biodegradable, non-hydrophobic, and enriched in hydroxyl groups
Tannin (fruits, roots)	Tannin molecules typically include at minimum 12 hydroxyl groups and at minimum 5 phenyl groups that serve as protein binders. Hydrolyzable tannins, condensed tannins, and pseudo tannins are the three basic types of tannin.	Dissolve in water and alcohol, but loosely soluble in chloroform and other organic solvents; bitter taste that is able to account for the dry preference in someone's mouth when unripen fruit is ingested
Chitosan	Chitin is treated with an alkaline substance (deacetylated beta-1, 4-Dglucosamine linear polysaccharide) to form it.	The degree of acetylation and molecular weight have a big impact on its characteristics. Non-toxic and biodegradable. It chelates numerous transitional metal ions and possesses highly reactive amino and hydroxyl groups.
Lignin	An amorphous, non-unique structure that varies depending on the species. Make up by three phenyl propane monomers: • Coniferyl alcohol (found in softwood), • Syringyl alcohol (found in hardwood) • Coumaryl alcohol (found in grasses and crops)	Not dissolvable in unreactive solution, and it contains several reactive functional groups such as hydroxyl and methoxyl groups.

capabilities than xerogels owing to their larger surface areas and pore diameters (20% and 22% more, respectively), but the challenging synthesis procedure of aerogels makes xerogels more cost-effective. Xerogels are made by evaporating the solvent; however, aerogels need an extra step of substituting the solvent with a supercritical fluid, which is a time-consuming and inefficient procedure (Pillai and Kandasubramanian, 2020). Furthermore, carbon xerogels are a common and efficient adsorbent for dye contaminants in water systems (Ptaszkowska-Koniarz, Goscianska and Pietrzak, 2018). Additionally, this material has a hierarchical structure of pores that develops across two phases of production. The first stage is attributed to the formation of mesoporous structure during the sol-gel process as a consequence of phase separation, while the second stage is associated with the formation of microporous structure as an outcome of carbonization (Shouman and Fathy, 2018). According to Ptaszkowska-Koniarz *et al.* carbon gels are currently synthesized via polycondensation of hydroxylated benzene derivatives (resorcinol) and aldehydes (formaldehyde) in the addition of solvent (water) (Ptaszkowska-Koniarz, Goscianska and Pietrzak, 2018).

Currently, many effective oil sorbent materials of carbon aerogels have been extensively developed (Long et al., 2021). Biomass-based carbon aerogels are more cost-effective, environmentally acceptable, and have nearly limitless precursors, they have sparked a lot of attention and demonstrated good electrocatalysis and absorption performance (Sam et al., 2020). Carbon aerogels are frequently used as the selective adsorbent for oil/water separation due to the intrinsic characteristics (Gan et al., 2019). The lower the surface hydrophobicity, the less water competes for adsorption but the high hydrophobicity of the surface allows for spontaneous oil uptake. Adjusting the surface functional groups and intelligently constructing hierarchical surface textures can improve surface hydrophobicity. The density of carbon aerogels is the second factor to consider where it is determined by the porosity, and the pores provide the space for storage of the absorbed oils. Hence, the density is inversely proportional to the calculated absorption capacity.

3.5.1. Synthesis and modification

Previous study reported on the production of carbon aerogels as follows: (I) the gelation stage includes the generation and strengthening of the gel via sol-gel and ageing processes; it's important to note that the ageing process was considered one of the gelation stage's steps. (II) drying, which is the process of obtaining aerogel by drying the gel at room temperature, in the freezer, or at supercritical circumstances. (III) carbonization, the process of forming carbon aerogel by carbonizing it at a high temperature in a nitrogen-rich environment (Gan et al., 2019). CAs are usually synthesized via polymer/monomer polymerization (gelation) followed by acetone exchange, supercritical carbon dioxide drying, and pyrolysis (carbonization) under vacuum (Yu, Li and Wang, 2017). Another process for preparing CAs is the polycondensation of organic compounds, such as resorcinol/formaldehyde (RF), cresol/formaldehyde, phenol/formaldehyde, phloroglucinol/formaldehyde, 5-methylresorcinol/ formaldehyde, and cresol/resorcinol/formaldehyde (Sabzehmeidani et al., 2021). The hydrogel is produced during the gelation stage through polymerizing and/or crosslinking a single precursor molecules (Gan et al., 2019). To produce a gel, the solution is heated at high temperatures for a period of soaking time to form a gel. After that, the gel is treated with an organic solvent to substitute the aqueous solvent (Hu et al., 2019). The resorcinol anion, which had a strong nucleophilic addition capacity driven by the negative charge and could easily combine with formaldehyde to create hydroxymethyl resorcinol, formed when resorcinol lost protons under alkaline condition. Acid catalysts have been increasingly introduced in recent years. Unlike under alkaline condition, the acid catalyst system primarily enhanced the electrophilicity of formaldehyde, and the electrophilic addition of formaldehyde to resorcinol resulted in the formation of hydroxymethyl resorcinol (Gan et al., 2019). Fig. 11 summaries the fabrication procedure of carbon aerogels.

The second step is solvent exchange stage. Once the final gel is produced, organic solvents should be used to replace the aqueous solvent. In other words, excessive water is removed from a wet gel by washing it many times with new methanol/acetone (Hu et al., 2019). It aids in the reduction of shrinkage and cracking of wet gels during the drying process. The third stage is the drying process. Presently, ambient pressure drying, supercritical drying, and freeze-drying are the three most common drying methods. The three drying procedures and their impacts on resulting characteristic can be seen in Table 4.

In brief, drying of the wet gel by environmental drying, supercritical drying, or freeze-drying of a wet gel yields an organic xerogel, aerogel, or cryogel, correspondingly (Sabzehmeidani et al., 2021). Through the carbonization process, the aerogel is heated at a high temperature (600°C) under an inert atmosphere of N_2 or Ar, and oxygen and hydrogen components are disintegrated into gases and released from the aerogel to produce carbon structure by a high temperature reaction (Gan et al., 2019). The carbonization of an organic gel is the process of transferring oxygen- and ammonia-containing functional groups in the gel to gases via high-temperature reactions, leading to the generation of carbon structure (Hu et al., 2019). In this point of view, the organic aerogels become a carbon network that is electrically conductive. During pyrolysis, the carbon aerogels derived from resorcinol/formaldehyde (RF) aerogels maintain their large specific surface area (400–800 $m^2\ g^{-1}$), high specific mesoporous volume ($> 0.55\ cm^3\ g^{-1}$), and the isotherms with such a hysteresis loop of their parent organic aerogel (Zubair et al., 2019). The carbonization factors, such as carbonization temperature, heating rate, and holding duration, as well as the catalyst concentration in the initial synthetic solution significantly influence the structure of carbon aerogel (Hu et al., 2019). Moreover, CAs produced from biomass materials have also received a lot of interest because of their low cost, environmental friendliness, and renewability. Chitosan, watermelon, starch, bagasse, lignin, bamboo, cotton, cellulose, and glucose, are some of the elements that may be used to make CAs. On top of that, CAs have been explored in a variety of applications, including

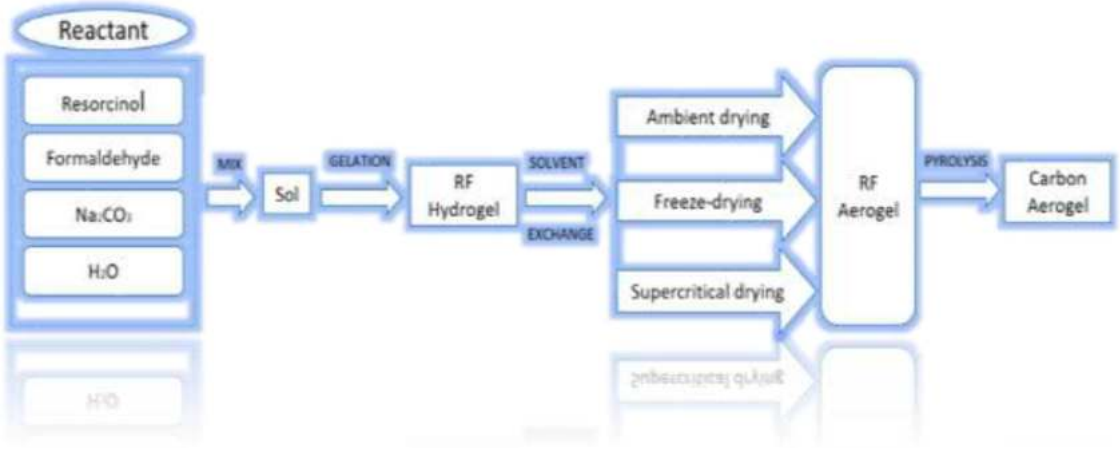

Fig. 11. Carbon aerogels fabrication procedure (Hu et al., 2019).

Table 4
Three drying procedures and their impacts on resulting characteristic (Hu et al., 2019).

Drying procedure	Drying conditions	Impacts
Supercritical drying with CO_2	Supercritical state condition (high temperature and high pressure)	• Dried polymers production called "aerogels" • Promotes insignificant shrinkage of pores structure • Large surface areas and pore volumes
Freeze-drying	Frozen condition (low temperature and vacuum)	• Dried polymers production called "cryogels" • Based on sublimation of frozen solvents • Cryogels are mostly mesoporous
Ambient pressure drying	Atmospheric condition	• Dried polymers production called "xerogels" • Promotes significant shrinkage

supercapacitors, hydrogen storage, batteries, sensors, electro-Fenton oxidation, adsorbents, and purification (Sabzehmeidani et al., 2021).

3.5.2. Limitation of carbon aerogel

Carbon aerogels are recognized as fascinating materials for environmental clean-up because of their unique and adaptable physical features. Nonetheless, one of the limitations of carbon aerogels is that their synthesis procedures are extensive, and many of the precursors are pricey, leading to large manufacturing costs. Moreover, under ambient pressure drying, the high capillary tension promotes structural shrinkage and collapse. In many cases, supercritical and freeze-drying procedures are used to circumvent this, which increases the operational risk and cost of preparation. Furthermore, most pristine carbon aerogels are brittle, affecting sorbent regeneration particularly for several water treatment applications. Lastly, a significant fraction of carbon aerogels have amorphous micro-morphological characteristics, which limits their selectivity in some applications (Gan et al., 2019).

3.6. The large-scale applications of carbon materials

Physical activation is preferable on an industrial scale because it allows for better control over the micro-porosity development during the pyrolysis stage (Pallarés, González-cencerrado and Arauzo, 2018). The need for activated carbon is growing due to the rising value of carbon materials in pollution control, and the gap between demand and supply is widening. As a result, the cost of activated carbon is escalating, and its application is becoming more limited. This is because of the use of non-renewable and highly expensive starting materials such as coal or petroleum pitch, which are both exhaustible and unjustifiable in pollution control applications (Lewoyehu, 2021). Furthermore, considerable inconsistencies between practical and theoretical absorption capacities frequently occur, resulting in non-ideal surface conditions, which appear to be a barrier to the widespread use of new materials in wastewater treatment.

Even though the present synthetic methods appear to be promising for large-scale material synthesis graphene, more research into the control and refining of particles with similar properties is required (T. Smith et al., 2019). According to Safian *et al.* (Safian et al., 2021), There is no effective way to ensure high-quality graphene than via a CVD process. It can also get around the most difficult stage, which is transferability. However, due to the method's circumstances, this methodology is less ideal. For the scaling-up procedure, chemical exfoliation is the ideal approach. Quality, purity, and cost efficiency are superior to any other technique now available. Additionally, the process can be used with mechanical exfoliation to improve the purity and quality of graphene (Safian et al., 2021).

Commercial applications of carbon nanotubes have yet to realise their full potential, and there is still room for waste-based CNT manufacturing as a complement to large-scale CNT production. Existing CNT production methods are energy and resource intensive, and include laser ablation, catalytic chemical vapour deposition (CVD), flame synthesis, and a solar energy approach. CVD has become the most promising and preferred method for large-scale manufacturing among these methods (Manawi and Atieh, 2018). Low-cost feedstock, increased efficiency, reduced energy consumption, and waste reduction are the primary variables influencing the scale-up of CVD-produced CNTs. Nevertheless, researchers are still looking for more efficient and cost-effective ways for large-scale production of CNTs. Synthesizing high-quality CNTs and graphene on a big scale is difficult due to the need for advanced equipment and many chemical reactions (Wang et al., 2020).

Field studies are becoming increasingly important, as evidence of field success is required before large-scale applications. Biochar composites have shown to work well in the laboratory in a number of experiments but field studies are extremely rare (Wang et al., 2022). Based on the paper published by Tisserant et al. (2022), The biochar potential from forest residues is anticipated to be applied annually to the grain producing area in Norway, which is estimated to be 0.28 Mha (35 % of the cultivated area) on average for the period 2010–2020. According to

the amount of forest residues available in the counties and pyrolysis biochar yields, a nationwide biochar production potential of 0.48 ± 0.03 Mtonnes per year is projected. Biochar adsorption is currently being used in small-scale wastewater treatment because it has a good adsorption impact on heavy metal removal. However, before upscaling, more research into the quantitative characterization of biochar heavy metal adsorption mechanisms and the disposal of biochar after adsorption to reduce environmental hazards is needed (Chai et al., 2021).

Despite its numerous advantages, carbon aerogel still faces numerous limitations in its application, including its high manufacturing cost. Considering resorcinol is a costly chemical and supercritical drying is an energy-intensive process, large-scale commercial manufacture is difficult (Sam et al., 2020). As a result, while producing scaled high-performance CAs using simple and sustainable methodologies is highly desirable, it remains a difficult task (Wang et al., 2020). However, Wang et al. (2020) propose an environmentally acceptable technique for the scalable synthesis of ultralight and super porous CAs based on agarose (AG) biomass, which is inexpensive and abundantly available.

3.7. Major factors on the performance of carbon materials

During the last decade, the study of carbon-based nanomaterials as adsorbents has gained in popularity. The development of this discipline is being driven by the unique properties and diversification of carbon-based structures, as well as the appearance of new opportunities in various subfields of chemistry, physics, and engineering. A number of methods can be used to adsorb a wide range of water contaminants, including harmful metal ions, medications, pesticides, metalloids, and other inorganic and organic substances.

Due to their availability and carbonaceous nature, biomass wastes have a lot of potential as such materials. As a result, the negative environmental effects of improper garbage disposal can be reduced. Carbon-based materials, which include activated carbon (AC), carbon nanotubes (CNTs), and graphene (GN) analogues, are powdered or bulk non-metallic solid materials with carbon as the major constituent. Large specific surface area, plentiful pore structure, strong thermal stability, high mechanical strength, high adsorption capacity, and tunable shape are all advantages. Some research have looked at modified AC, CNTs, or GN analogues as adsorbents, but the specific criteria for modification and the underlying mechanisms still have not been properly explained (Liu et al., 2019) (Wang et al., 2020). In addition, because the modification methods or adsorption mechanisms used in these research are comparable, a summary can be useful in examining carbon-based adsorbents as a whole for heavy metal removal, as well as the regeneration strategy.

The surface area and pore structure of carbon materials are used as a criterion for classifying them as excellent or poor adsorbents (Santoso et al., 2020). For example, according to Santoso et al. (2020), on a laboratory scale, carbon-based adsorbents have a lot of potential for isolating MB from aqueous solutions. The characteristics are important for accommodating absorbed MB and determining carbon adsorption capacity. Aside from surface area and pore structure, MB adsorption was influenced by carbon particle size, surface acidity, and functionality, all of which influenced the MB-carbon interaction. In general, the surface area of carbon adsorbent has a significant relationship with their adsorption ability. The trend does not apply to all carbon adsorbents, as some carbon with a large surface area had a poor adsorption capacity. Since surface area has a positive effect on carbon adsorption capacity, increasing the pore diameter of the adsorbent does not always result in increased adsorption capacity.

4. Derivation of carbon based material from biomass waste

Biomass materials are ubiquitous in our environments, and their low cost, accessibility, environmental friendliness, carbon richness and recyclable qualities make them as the great candidates for carbon materials supplies (Yang et al., 2019,Ma et al., 2017). Activated carbon has been made from a variety of wastes, including coconuts, peat, residual sludge, industrial process ash, rice husks, and others (Streit et al., 2021). Natural biomass-derived carbons has sparked the attention as ideal substitutes for conventional carbon sources in a variety of applications (Tang et al., 2017). Agricultural and forest wastes are one of the most generally utilized biomasses for the fabrication of BCs due to their low cost and abundance of natural resources. Each year, agriculture, logging, and other human activities produce tonnes of different residues such as rice husks, straws, and wood chips. Large quantities of lignin and cellulose are present in the biomass resource, thus provides as better choice for the fabrication of low cost BCs (Huang et al., 2019).

Carbons derived from biomass materials are inherently porous or hierarchically organized, making electrolyte penetration easier and reducing ion diffusion distance. Besides, most natural biomass materials contain nitrogen, boron, and other elements that may be treated as heteroatoms to provide additional active sites. Interestingly, certain biomass is recycled from agricultural or regular wastes like bamboo chopsticks and straws, making the process both cost-effective and environmentally beneficial (Tang et al., 2017).

As for adsorption process, adsorbents produced from biomass waste have gained a lot of interest because of their low cost, plentiful renewable raw resources, and environmental friendliness (Dai et al., 2020, Jiao et al., 2021). There are two types of biomass-derived adsorbents; (i) biomass-derived carbon-based materials made by carbonizing biomass feedstock and (ii) biomass-based composites made by directly functionalizing biomass feedstock (Jiao et al., 2021). In the wastewater treatment context, the application of biomass-derived carbon based materials such as biomass-derived activated carbon (BAC) and biochar are believed to be applied for phosphate removal from wastewater due to its highly developed porosity structure. Green biomass materials can be utilised to eliminate pollutants from the aqueous environment in wastewater treatment. Nevertheless, in terms of commercial uses, the biomass materials for wastewater treatment have continuous difficulties in terms of large-scale manufacturing, structural stability, and efficiency.

Alternatively, as the wastewater treatment preferred a low-cost and low-energy investment, the application of waste material adsorbents in wastewater treatment has grown in popularity with simultaneously improve the circular economy concept through waste material reuse and recycling (Hossain et al., 2020). In line with Kaetzl et al. (2019) explanation on the farm-wastewater treatment in Sub-Saharan Africa, the common agro-residues such as rice husk biochar have been successfully applied, as two-stage anaerobic filter materials where the treated wastewater was set to use for irrigation purpose. This method proved very cost-effective and efficient in eliminating chemical oxygen demand, with a removal rate of up to 94%. On the other hand, another study by Hossain et al. (2020) on the low cost adsorbents stated that naturally available sources (red mud, peat, brown coal), industrial waste (waste from sugar and tea industries, paper mills), agricultural residues (like fruit shells, straw, husk), bagasse, slag, wood residues (sawdust), sludge, unburned carbonaceous materials, as well as other waste materials have been believed to adsorb and remove 60 to 100% of emerging contaminants (ECs) including heavy metals (Cu, Zn, Pb, As, Ni, Cd, Cr) and chemical compounds such as phenol, acids, acetone, toluene, chloride, fluoride, nitrate from the wastewater.

4.1. Sewage sludge

Residual sludge is a significant barrier for wastewater treatment facilities since it is a common by-product with a complicated and costly disposal method (Grassi et al., 2020). The utilization of this waste as a precursor material to produce activated carbon for pollutant adsorption seem to be a viable alternative in comparison with the conventional disposal techniques for example landfill or incineration (Streit et al., 2021). As sewage sludge is a carbon-rich, sustainable, and abundant

resource that can be acquired at a cheap cost, it could be utilized to produce the activated carbon (AC) adsorbents, which are used to remove a range of pollutants from air and water. Sludge has been proven to create high-quality carbons for the adsorption of metals, phenols, and colours in water (Björklund and Li, 2017). Producing AC from sludge is believed to be a cost-effective option in terms of waste management and low-cost adsorbent manufacturing. The sludge-based carbon production costs are dependent on factors such as sludge availability and processing requirement, notably energy costs for pyrolysis and drying (Björklund and Li, 2017).

According to the study by Godlewska et al. (2019), carbon-based adsorbent derived from sewage sludge (SSL) or sewage sludge-biomass mixture in environment of nitrogen (N_2) or carbon dioxide (CO_2) at temperatures of 500, 600, and 700°C, was used to adsorb phenanthrene and pyrene. This study aimed to see how biomass addition to sewage sludge and CO_2 application during pyrolysis affected the adsorption properties of biochars made from SSL and SSL-biomass mixture in relation to selected polycyclic aromatic hydrocarbons (PAHs), such as phenanthrene (PHE) (3-ring) and pyrene (PYR) (4-ring). The result from the study indicated that the biomass addition to sewage sludge before pyrolysis reduced the PHE and PYR affinity (log K_{oc}) for biochars. PHE and PYR adsorption (based on log K_{oc}) on biochars with biomass was lower, ranging from 9 to 14 % and 4 to 6 %, respectively in comparison with biochars made only from SSL (with N_2 as carrier gas). Similar to the biochars made only from SSL, the biochars made at a temperature of 700°C had the greatest affinity for PHE and PYR. According to Jin et al. (2018), the decreased affinity of PHE and PYR for SSL-biomass biochars compared to SSL only biochars could have been due to the effect of the steric hindrance.

Meanwhile, Ngambia et al. (2019), investigated the adsorptive purification using Mg(II) loaded sewage sludge-derived biochar (SDBC) adsorbents composite for wastewater contaminated with heavy metal lead (Pb), cadmium(Cd) silver (Ag) and copper (Cu). By using sewage sludge waste as a carbon template and abundant non-toxic $MgCl_2$ salt in a condition where Mg(II) loading of 25% and calcination temperature of 500°C, a surface carved rod-like SDBC-25 % Mg(II)-500 was produced through a simple precipitation-calcination process. The schematic illustration of the SDBC-a % Mg(II)-T synthesis and proposed morphological structure modifications is shown in Fig. 12. The use of sludge as the carbon source resulted in the production of porous structures, tunnels, and surface MgO carving. The surface morphology and textural features revealed surface carved rods with multiple tunnels with a surface area of 91.57 $m^2\ g^{-1}$, and phase analysis revealed that Mg(II) was successfully incorporated on the rods' surface.

Based on this study data analysis, it shows that SDBC-25% Mg(II)-500 proven to be successful in removing heavy metals (Pb^{2+},Cd^{2+}, Ag^{+}, and Cu^{2+}) from several types of real water, with an adsorbent dosage of $1gL^{-1}$ achieving around 99 % metal ion removal. Batch adsorption data were best characterised by the Langmuir isotherm model, which had a capacity of 2931.76 mg/g^1 and 861.11 mg/g^1 for Pb (II) and Cd(II) respectively, showing that chemisorption is mostly the type of adsorption to occur.

4.2. Lignocellulosic

Lignocellulosic biomass, for instance, corn stover, alfalfa stems, corn cobs, wood, sorghum stalks, cotton residue, wheat straw, fast-growing plants like grass, and bagasse (Demirel, 2018). While non-lignocellulosic biomass is predominantly made up of carbohydrates, lipids, and proteins, it also contains human and animal wastes, microbes, and their metabolites (Omoriyekomwan et al., 2021). Lignocellulosic biomass is a natural, non-toxic, ubiquitous, sustainable, and renewable resource that may be used in a variety of manners (Jabarullah, Kamal and Othman, 2021). Lignocellulosic biomass is characterized by natural porousness, a hierarchical structure, and a high surface area (Tang et al., 2017). The porous structure is advantageous because it allows for ion movement; it may also be easily mixed with other materials to create a hybrid material with improved electrochemical characteristics (Xiao et al., 2017). Lignocellulosic is also known as a carbon-rich material with heteroatom-doping properties, which makes it appealing for application as a carbon-replacement material (Tang et al., 2017). Due to its biodiversity, distinctive microstructure, and excellent conductivity, biomass-derived carbon compounds have sparked a huge amount of attention (Jabarullah, Kamal and Othman, 2021). The examples for lignocellulosic biomass includes rice straw and husk, coconut shell, palm oil, tree bark waste, and bamboo.

4.2.1. Rice straw and husk

Rice farming is widespread, and it is one of the world's most important sources of food, particularly in Asia. Every year, the demand for rice grows fast, and by meeting those demands, agriculture waste is magnified (Safian, Haron and Ibrahim, 2020). Rice is the main meal for a large portion of the world's population, especially in Asia and Africa, however its yearly production produces massive amounts of straw (estimated at ~8×10^{11} kg) and husks (~1.5×10^{11} kg) (Goodman, 2020). The waste produced is commonly rice husk which is recycled for power as fuel source due to its high calorific content (Safian, Haron and Ibrahim, 2020). The by-product of this operation is rice husk ash (RHA), which accounts for 25% of the raw resources (Hossain, Mathur and Roy, 2018). Lignocellulose materials and mineral compounds are the two main components of RH. Furthermore, during RH's growth, silica also becomes a component of the RH (Alam et al., 2020). Rice husk has a high concentration of silica and ash, makes it an ideal raw material for cement (Sandhu and Siddique, 2017), fuel, activation carbon, adsorbent (Safian, Haron and Ibrahim, 2020). RH is a kind of lignocellulose biomass that is a renewable biomass that contains between 28 and 30% inorganic (mostly silica) and 70 to 72 percent organic components (Alam et al., 2020).

Rice straw and husks include a mixture of lignin (35%), cellulose (25%) and hemicellulose (20%) (Hossain, Mathur and Roy, 2018), as well as significant quantities of silica and other minor components. As seen in Table 5, rice straw and husks include a mixture of cellulose,

Fig. 12. Schematic illustration of the SDBC-a % Mg(II)-T synthesis and proposed morphological structure modifications retrieved from (Ngambia et al., 2019).

hemicellulose, and lignin, as well as significant quantities of silica and other minor components. Polysaccharides include cellulose and hemicellulose. Polysaccharides include cellulose and hemicellulose. These polymers combine in cell walls to produce lignocellulose, a complex three-dimensional structure in which cellulose is encircled by a monolayer of hemicellulose and incorporated in a matrix of hemicellulose and lignin (Goodman, 2020).

Because rice husk carries about 20% silica, pre-treatment with potassium hydroxide or sodium hydroxide is necessary for most biomass applications. After the thermal process, the silica in the rigid layer of the structure stays as a by-product with ash (Safian, Haron and Ibrahim, 2020). RH has distinctive physicochemical and biological characteristics, providing it an ideal raw material for the production of AC (Alam et al., 2020). During char preparation, lignin acts as the vital element (Alam et al., 2020). Low carbon yields are correlated with cellulose and hemicellulose, and these volatile portions withdrawn during pyrolysis contribute in the establishment of microspore AC development (Rodriguez Correa, Otto and Kruse, 2017). Furthermore, activated carbon made from rice straw via carbonization and activated with KOH has a good adsorption capacity for aqueous solutions of bisphenol A, carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate), and the pesticide (Goodman, 2020). The use of RH for the synthesis of AC can be a superior choice with low-cost synthetic methods, and it has a lot of promise for many applications that can be further studied at actual level or future industrial uses (Alam et al., 2020). In the case of graphene, the amount of KOH used has an effect on the shape of the graphene generated. In the carbon structure activation, KOH improves the specific surface area of graphene by opening the carbon structure. The thermal treatment will take place followed by desilication and activation (Safian, Haron and Ibrahim, 2020).

Rice husk (RH)-based porous composites were also made as a low-cost adsorbent that was readily accessible. RH has a naturally formed porous structure, whereas porous nitrogen rich monolithic carbon (HPC) has a specified macropore and mesopore structure (Thambiliyagodage et al., 2020). Two factors must which are carbonization temperature and activation agent have to be regulated in order to generate porous carbon with a large specific surface area (SSA) and an appropriate pore size distribution (Li et al., 2021). The ability to construct porous carbon with ultrahigh SSA via a simple activation process is one of the most notable desirable features of the biomass precursor, and the customary carbonization of biomass at various temperatures under inert atmosphere is a widely used method for the preparation of biomass-derived porous carbon (Wang and Hu, 2018). Rising thermal treatment temperature leads to expand in pore size, specific surface area, and outer pore volume (Sun et al., 2019). To exemplify, quinoa husk (QH) was used as the basic material to create a porous carbon material. The generated carbon material, PC–QH, has a wide surface area and a high rate of porosity after the carbonization and chemical activation with KOH procedures (Chen et al., 2018). In general, RH characteristics are influenced by a range of factors, including geological location, rice type, climatic fluctuation, paddy farming practices, and fertiliser application (Alam et al., 2020). Ariffin *et al.* reviewed the rice husk derived graphene that activated with potassium hydroxide (KOH) which aids in the production of pores the generation of high purity graphene material with stable and clean edges (Arifin et al., 2020). Graphene is made by activating rice husk with KOH and sintering it at 900°C, according to Singh and colleagues. When examined using TEM, the findings demonstrate that the generated graphene contains a few layers of graphene with aggregation of silica particles (Singh, Bahadur and Pal, 2017).

Table 5
Major components of rice straw and husks (%) (Mirmohamadsadeghi and Karimi, 2020).

	Cellulose	Hemicellulose	Lignin	Ash
Straw	32.0–38.6	19.7–35.7`	13.5–22.3	10–17
Husk	28.6–43.3	22.0–29.7	19.2–24.4	17–20

Based on the research by Khoshnood Motlagh, Asasian-Kolur and Sharifian (2020), a comparative study on the production of carbonaceous adsorbent and silica using rice straw and rice husk was conducted. Rice husk and rice straw were used as the raw materials for activated carbon (AC) and silica synthesis and the main characteristics of the resulting products were compared. Fig. 13 shows the FESEM micrographs of silica nanoparticles extracted from RHA and RSA. Both raw materials were carbonised for 1 hour in an inert environment at 700°C to form rice straw ash (RSA) and rice husk ash (RHA) biochar before the materials were subjected to the following AC production and silica extraction processes. The data analysis shows that AC made from rice straw had a greater surface area and total pore volume (2229 m^2 /g and 1.6 cm^3 /g) than AC made from rice husk (1941 m^2 /g and 1.5 cm^3 /g) when made at 1000°C with a 1.5 impregnation ratio. Meanwhile, the RSA has a higher silica extraction yield than RHA, whereas RHA has a 15% higher silica production yield. In addition, unlike the solid gel form of RH-based silica, which requires crushing, the silica derived from rice straw has a powdered form.

4.2.2. *Coconuts shell*

Coconut-based agricultural wastes have drawn a lot of interest as an innovative adsorbent for removing a variety of contaminants from industrial effluents (Piriya et al., 2021). Coconut shells are used as raw materials for production of activated carbon because of their plentiful supply, large density, and purity, as well as a clear environmental advantage over coal-based carbons, especially in terms of acidification potential, non-renewable energy needs, and carbon footprint principle (Muzarpar et al., 2020). According to Shukla *et al.* (Shukla et al., 2020), raw material (coconut shell) 250 g was taken, cut into minor pieces, rinsed with tap water, and dried for 24 h throughout the sunlight. For 1 h, the coconut shell was burnt at 300°C. The lower temperatures produce better results in the carbonization process compared to high temperatures. Carbonization of shells is influenced by a number of parameters, including presence of an inert environment, temperature of carbonization, heating rate, and process residence time among the first one has the greatest impact (Piriya et al., 2021). Different components of coconut, such as coir and shell, have been extensively investigated as bio-sorbents for the removal of dyes, heavy metals, and organics from aqueous solutions, rendering it one of the most important agricultural wastes used for wastewater treatment (Bandara et al., 2020). Agricultural by-products and other lignocellulosic materials are extremely appealing feedstocks for sustainable AC production; their usage could even reduce greenhouse gas (GHG) emissions by preventing emissions when they degrade or are burned (Muzarpar et al., 2020). The pulverised coconut shells were placed in 100 ml of concentrated phosphoric acid (H_3PO_4) for 24 hours to activate the acid. This will assist in improving the porosity of activated carbon while also raising the surface area available for the adsorption mechanism (Shukla et al., 2020). Base on Irfan et al., 2018,Muzarpar et al. (2020), the pore volume, pore size, and surface area data for coconut shell activated carbon were defined as adsorbent pores, which can be categorised as micropores (less than 2nm), mesopores (2–50nm), and macropores (greater than 50nm) based on the International Union of Pure and Applied Chemistry's description. The previous study on coconut shell production is shown in Table 6.

4.2.3. *Palm Oil*

With approximately 950,000 hectares of land, Malaysia is one of the world's major palm oil producers (Nasir et al., 2017). In Southern Thailand, palm oil production is one of the most important industries. Palm oil mill wastes, including oil palm fibres, empty palm fruit bunches, and palm kernel shells, have been produced in large quantities in recent years (Promraksa and Rakmak, 2020). It is predicted that yearly production of palm oil in Malaysia may estimate over 15.4 million tonnes between 2016 and 2020 (Nasir et al., 2017). Oil palm

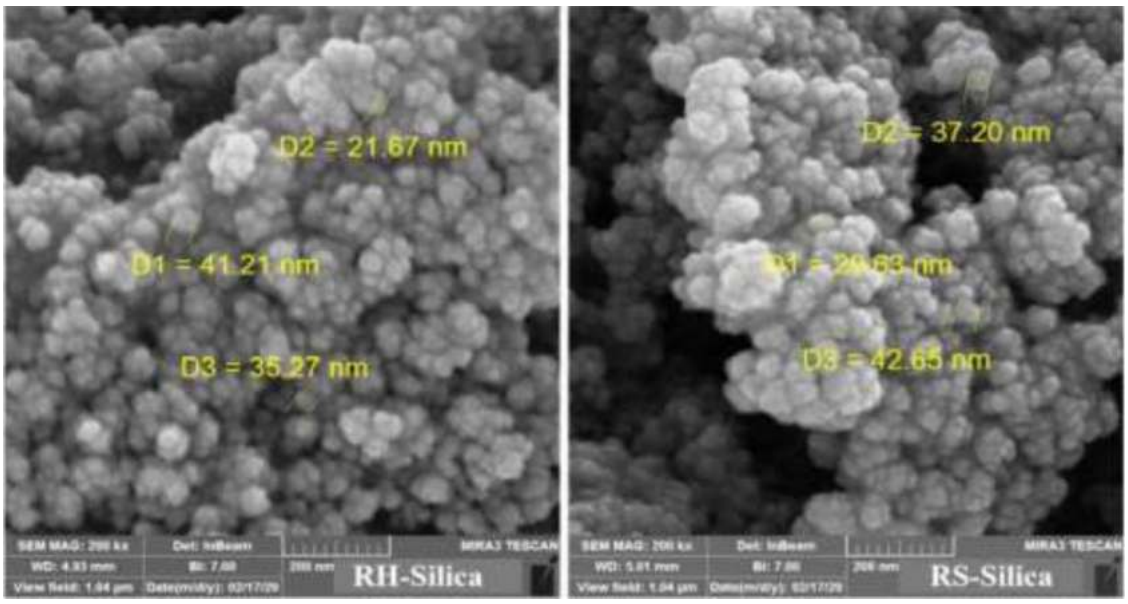

Fig. 13. FESEM micrographs of silica nanoparticles extracted from RHA and RSA retrieved from (Khoshnood Motlagh, Asasian-Kolur and Sharifian, 2020).

Table 6
Previous research on coconut shell production for activated carbon (Muzarpar et al., 2020).

Material	Carbonization temperature (°C)	Post heat treatment	Physical activation process	Chemical activation process	Function/element of study
Coconut Shell	450	110°C for 11 hour	-	H_3PO_4	Adsorption of reactive blue 19 dye
	450	110°C for 2 hour	-	H_3PO_4	Electrochemical capacitors
	500	110°C for 24 hour	-	H_2SO_4	Adsorption of textile dyes
	200	105°C for 24 hour	Hydrothermal process	-	Methylene blue adsorption
	-	105°C for 48 hour	-	KOH	Adsorption of benzene and toluene

agricultural activities hold the biggest industry of agriculture in Malaysia with about 5.7 million hectares of plantation land in 2016 (Liew et al., 2018). In fact, the oil palm industries create a large amount of lignocellulosic biomass daily. Oil palm trunks (OPT), oil palm fronds (OPF), empty fruit bunches (EFB) and palm pressed fibres (PPF), palm kernel shells (PKS), palm oil mill effluent palm (POME), and so on are all included as the lignocellulosic biomass. The truth of the matter that waste accumulated by oil palm activities is causing severe disposal issues (Nasir et al., 2017). The quantity of palm oil mill wastes is quickly increasing and will eventually become a serious concern from now onwards (Promraksa and Rakmak, 2020). Table 7 summaries the percentage of primary composition of oil palm waste oil.

In 2016, the *Elais guineensis*, or oil palm, thrived, resulting in a significant rise in oil palm plantation area in Malaysia of more than 5.74 million hectares. The quantity of waste produced has increased in tandem with the fast development of palm oil production. An approximate 85.5% of agricultural wastes in Malaysia came from palm oil plantations. Palm oil plants accounted for approximately 85.5 % waste in Malaysia. Empty fruit bunches (EFB), shell and kernels, fronds, leaves, and trunks form the majority of the oil palm biomass waste. The large quantity of waste produced must be efficiently managed to encourage sustainability (Faridah et al., 2018). Specifically, the wastes accumulated during the generation of the 76 million metric tonnes (MT) of palm oil are highly crucial since they account approximately 20% of the total waste generated in the palm oil processing line. The annual worldwide waste output from oil palm is approximately 500 MT, including palm trunks, fronds, and other wastes (Ukanwa et al., 2020). Pursuant to Faridah et al. (2018) the percentage of oil palm in Malaysia for the year 2009 were illustrated depending on each of oil palm biomass; shell 5%, frond 59%, trunk 18%, leaves and mesocarp fibre 10%, and empty fruit bunch 8%. Besides, Faridah et al. (2018) also explained the percentage for recyclability work of 8% oil palm empty fruit bunch accordance to Table 5. As stated, 1.0 % for saccharification, 1.1% of feedstock, 1.3% of filler, 0.1% of biodiesel, 2.6% of energy, and 1.9% of adsorbent.

Green technology is widely seen as a powerful economic stimulant and a way of reducing environmental deterioration, particularly in developing nations (Nasir et al., 2017). In the last few years, increasing prices and environmental concerns have prompted the adoption of novel low-cost adsorbents generated from renewable materials (Faridah et al., 2018). Natural precursors have become an excellent prospects as they potentially appeared to be the green options for industrial-scale synthesis of carbon nanomaterials such as carbon nanotubes (CNT), graphene, graphene oxide (GO), graphene quantum dots (GQDs), reduced

Table 7
Percentage of oil palm waste oil primary composition (Faridah et al., 2018).

The oil palm waste	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Inorganic Compounds (%)	Waste Percentage Generated from Palm Oil Industry (%)
Empty fruit bunch	25	28	27	16	12
Frond	35	36	29	Not available	14
Shell	28	22	44	Not available	5
Trunk	50	70	20	Not available	Not available
Leaves/Mesocarp fiber	45	48	27	Not available	Not available

graphene oxide (rGO), activated carbon (AC), and others because they are not only renewable but also cost effective (Nasir et al., 2017).

The oil palm biomass could be used to develop new resources to tackle the waste management challenge. Activated carbon is one of the products that may be made from palm oil waste biomass. Activated carbon is indeed a high porous, amorphous carbon material with a large inter-particulate surface area (Hendriansyah et al., 2018). As it was transformed to activated carbon for the improvement of the adsorption process, the adsorbent generated from different components of oil palm biomass showed varied morphology in line with its composition (Table 5). Low molecular weight products such as anhydro-sugar, furan, acetic acid, carbonaceous chars, aldehyde, and hydroxyl are produced by biomass with a greater cellulose content. Unsaturated chain and phenolic compounds with greater molecular weight, such as eugenol, alcohols, carbonaceous chars, and styrene are generated when lignin decomposes at high temperatures (Faridah et al., 2018).

Palm waste, such as palm kernel shell (PKS) waste, is being used as a biofuel for steam generation since it heats up faster than other palm waste products. In addition, PKS is also appealing for use in the manufacture of activated carbon, concrete pavement, and polymer biocomposite due to its small size, simplicity of handling, and limited biological activity as well as owing to its reduced moisture content (Jabarullah, Kamal and Othman, 2021). More high-value applications are desirable, and one of them is AC, which has a wide range of applications in desalination, pharmaceuticals, gas storage, and water treatment because of its porosity (Ukanwa et al., 2020).

Oil palm waste (OPW) is a low-cost feedstock with a high carbon composition of up to50%, and making it a good choice for AC synthesis (Nasir et al., 2017,Liew et al., 2018). They are also satisfactory precursor for gasification, AC generation, and carbon fibre filament fabrication. However, as previously stated, it is a suitable precursor for AC synthesis, and the adsorption of heavy metals, dyes, organic and inorganic contaminants has been proven in numerous experiments using OPW-based AC. All of the OPW components normally comprise around 5, 6% hydrogen in the bound state of cellulose, hemicelluloses and lignin form (Ukanwa et al., 2020).

The OPW was believed to contain significant quantities of carbon (43–51 wt%) and fixed carbon (30–39 wt%), indicating that it has the potential to be transformed into carbon-rich biochar (Liew et al., 2018). The biomass wastes from palm oil processing might be converted into biofuel or other bio-products and utilized as a sustainable energy source. One possible procedure for mitigating these environmental problems is to transform palm oil wastes into biochar through the pyrolysis process (Promraksa and Rakmak, 2020). The process factors that influence the production of biochar from biomass are vital. In consonance with the current research by Promraksa and Rakmak (Promraksa and Rakmak, 2020) on biomass pyrolysis, the generation of biochar was shown to be dependent on numerous parameters, including pyrolysis temperature, carrier gas flow rate, biomass particle size, and other factors such as reactor design and catalyst. The data described that the greatest biochar production (44.91 wt%) was achieved from pyrolysis of palm kernel shells at 525°C with a particle size of 750 m and a nitrogen flow rate of 2 L/min (Promraksa and Rakmak, 2020).

4.2.4. Tree bark waste

Trees are among the world's biggest living organisms, and plants as a whole constitute one of our most important renewable resources. Forestry continues to offer raw materials for a number of purposes today, such as the construction sector, paper production, and different wood products (Wenig et al., 2021). After all, many tree components, like as reaction wood, branches, and bark, are thrown as forestry residues and waste wood, reused as additions in composite products, or burnt for energy generation. The transformation of bark into innovative carbon materials is one of the more advanced applications of bark (Wenig et al., 2021). On top of that, black wattle bark waste comprises of cellulose, lignin, hemicellulose, residual tannins and 2% of inorganics, which able to be utilised as a precursor material for activated carbon synthesis because of three factors: composition, availability, and waste management, black wattle bark waste (da Silva et al., 2018). The black wattle bark waste is an excellent material to exploit as a precursor material for activated carbon synthesis because of its high carbon content and low inorganic content (Lütke et al., 2019). The Brazilian Institute of Geography and Statistics (IBGE 2019) stated that around 136.000 tonnes of black wattle bark were produced in the year of 2017. This can be portray as a huge amounts of waste from tannin extraction factories were created, implying high availability and posing an environmental concern because this waste is often burnt.

In a modelled industrial wastes by Lütke et al. (2019), black wattle bark waste-activated carbon (BWBW-AC) was able to extract phenolic chemicals with a 95.89 percent efficiency. In conclusion, there were two significant elements to using black wattle bark waste as an alternate precursor material for activated carbon synthesis. First, the prospect of recovering a plentiful industrial waste, thereby adding value to it, and second, the application of a low-cost, effective adsorbent to extract phenol from an aqueous solution (Lütke et al., 2019). The employment of wood bark as a candidate material for removing heavy metal ions from wastewater is based on special interests; quantity of waste, technical and economic productivity of produced materials, and minimization of technogenic burden on the environment through economically feasible wastewater treatment technologies, high sorption capabilities (Vasilenko, Kiryushina and Semeykin, 2018). Moreover, Douglas fir and redwood barks were tested for mercury adsorption, whereas black oak bark had the maximum adsorption capacity for Hg, at 400 mg/g, and the lowest adsorption capacity for other heavy metals, such as Cd, at just 25 mg/g (Alalwan, Kadhom and Alminshid, 2020). In the context of chromium removal, plant bark (Acacia arabica, Eucalyptus) has also been described as a potential adsorbent material for chromium removal, with an effectiveness of more than 90% at optimal pH (Carolin et al., 2017). Furthermore, tree bark has been identified as a probable adsorbent for nickel removal in acidic pH ranges. The bark of *Acacia leucocephala* has the maximum adsorption capacity, with 294.10 mg/g (Alalwan, Kadhom and Alminshid, 2020). The presence of tannins in oak bark extracts makes them efficient for heavy metal ion removal from wastewater. Hydrolysable tannins (add water under the action of acids) and condensed tannins (not capable of hydrolytic cleavage) are the two types of tannins. Tanning agents are weak acids that function like negatively charged colloidal particles, forming clumps when they come into contact with positively charged heavy metal ions in the manner of precipitation (Vasilenko, Kiryushina and Semeykin, 2018).

The use of other parts of tree such as the wood waste apple branches as raw materials to prepare apple branch biochar were reported by Wang *et al.* (Wang et al., 2021), which basically being modified with Mg/Al layered double hydroxide to synthesize a novel carbon adsorbent to enhance the removal of nitrate (NO^{3-}) from wastewater. Based on this study, the modified apple branch biochar were able to remove NO^{3-} at the range of 83% averaged. In contrast, the modified apple branch biochar exhibits distinct advantages for nitrate adsorption as compared to other chemical modification techniques for straw or wood-based biochar (Wang et al., 2021). As for root part of biomass, the waste *from Hevea brasiliensis* rubber tree root were gasified for the sequestration of malachite green (MG) dye from the water bodies. By using carbon residues from gasified *Hevea brasiliensis* root, it was determined to be economically viable for commercialization due to its low manufacturing cost and maximum monolayer MG adsorption capacity was 73.5 mg/g respectively (Ahmad et al., 2021). Additionally, a long root based biomass such as *Eichhornia crassipes,* also acts as a precursors in the activated carbon fabrication (Ashiq et al., 2021). Activated carbon produced from this root structural-based biomass demonstrated strong adsorptive removal of fluoroquinolone based compounds; ciproflaxin with 145 mg/g and norfloxacin approximately 135.1 mg/g (Liu et al., 2019). These fluoroquinolone antibiotics compounds may penetrate the pores of AC and travel sideways, accessing a large number of adsorptive

sites due to their planar molecular configuration (Chen et al., 2018).

4.2.5. Bamboo

Bamboo is a perennial woody grass that belongs to the *Gramineae* family and the *Bambuseae* subfamily and is found all over the world (Azeez and Orege, 2018). Bamboo is found ubiquitously across the world, but it is especially abundant in tropical and subtropical locations, with China, Indonesia, and Thailand producing 12 million tonnes of bamboo annually (Parthasarathy et al., 2021). Bamboos are a fast-growing plant biomass that can be found in subtropical, tropical, and temperate regions (Sackey et al., 2021). Every year, a vast quantity of bamboo waste is produced, with a high content of lignocelluloses as a feasible resource that may be used to make char (Jawad and Abdulhameed, 2020). Due to its chemical composition and physical characteristics, this biomass has a great potential as a substitute for several lignocellulosic and non-lignocellulosic materials in a variety of applications (Azeez and Orege, 2018). Bamboo fibre has a chemical constitution that is identical to the of bast fibre. Cellulose is the major important component. It also has a better moisture holding capacity than flax, ramie, and cotton fibres because to its loose structure and the presence of disordered non-cellulose compounds. Because of these properties, bamboo fibre has become a potential carbon precursor for the production of different sorbent materials (Yuan et al., 2017). The chemical components of bamboo fibres can be seen in Table 8.

The three primary chemical components of bamboo are cellulose, hemicelluloses, and lignin, which are intimately linked in a complex composition. They account for around 90% of the total bamboo mass. Pigments, tannins, protein, fat, pectin, and ash are minor components. Others also involve resins, waxes and inorganic salts (Azeez and Orege, 2018). In the last two decades, the thermal treatment of waste bamboo into char and activated carbon products, particularly for water treatment applications, has piqued attention (Parthasarathy et al., 2021). Bamboo is use as a raw material for designing (fabrication, characterization, and implementation) of activated carbon is significant because it is a species with a high concentration of carbon and fibrovascular bundles, which are responsible for forming the activated carbon porous carbonaceous structure, as well as other characteristics such as rapid growth, high productivity, and small production circles (Santana et al., 2017). The use of AC generated from waste biomass, bamboo (BAMB-AC) for oil spill response is a promising approach since the surface area and adsorption capacity were determined by them (Ngofa et al., 2022). Increasing the impregnation ratio had no effect on the surface area of the bamboo activated carbons generated by activating the char with sulfuric acid at temperatures ranging from 723 to 1223 K. The activated carbons showed exceptionally high methylene Blue (MB) adsorption capabilities, with the high surface area carbon having an adsorption capacity of 2.35 mmol/g or 750 mg dye/g activated carbon. (Parthasarathy et al., 2021).

In the present study, bamboo furniture that has been thrown can be shredded and utilized as a raw material feedstock. At varied temperatures, namely 723–1223 K, the shredded bamboo powder was pyrolyzed to create bamboo biochars in a muffle furnace inerted with nitrogen at varying reaction durations. Bamboo-derived carbon chars have a very good dye adsorption ability. Methylene Blue uptake was above 1.1 mmol/g char, which is good relative to many chars (Parthasarathy et al., 2021). Through the pyrolysis technique, a new carbon aerogel (CA) was produced as sorbents utilizing the inexpensive and plentiful bamboo pulp fibres as precursors. CA has remarkable absorption capabilities for organic solvents/oils (50-150 g/g). Its organic solvent absorption was better to that of several other bio-based CAs (Yuan et al., 2017).

Table 8
Chemical components of bamboo fibres (Azeez and Orege, 2018).

Chemical components	Percentages proportion (%)
Aqueous Extract	3.16
Pectin	0.37
Hemicellulose	12.49
Cellulose	73.83
Lignin	10.15

4.3. Cotton based waste

A large quantities of textile waste is discarded of in landfill; textile waste contributes for 10–20 percent of landfill contingent on the nation (Sandin and Peters, 2018). One promising way of solving the problem is the application of cotton based textile waste as a precursor for carbon materials as a carbon material precursor as waste cotton is a widespread, biodegradable, and harmless resource because cotton is primarily a cellulose polymer (Nasri-Nasrabadi and Byrne, 2020). Natural fibres display several advantages over traditional polymer and glass fibres that is, low density, non-abrasive qualities, bio sourcing, biodegradability, low acoustic and thermal conduction, and better mechanical characteristics (Jagdale et al., 2017). Cotton can be a suitable material for the construction of high-performance catalysts and pollution removal from the environment due to its natural condition and price (Shirvanimoghaddam et al., 2019). Cotton is one of the most widely used natural cellulose fibres, which contain 90–95% cellulose while also the one of the finest sources of cellulose (Jagdale et al., 2017). Based on the Sartova *et al.* (Sartova et al., 2019) report, obtaining AC from yearly renewable cotton biomass through water steam activation in a short period (8 minutes), with a large yielding (56-65 percent of cotton stems) and good adsorption characteristics than industrial AC generated from wood. Cotton textile waste was used as a precursor to generate tubular activated carbon fibres with an exfoliated surface (Nasri-Nasrabadi and Byrne, 2020). Cotton has lately been employed in the environment in the form of aerogels (Shirvanimoghaddam et al., 2019) or graphene-oxide-coated cotton for oil elimination (Hoai, Sang and Hoang, 2017).

In the study by Shirvanimoghaddam et al. (2019), new carbon microtubes generated from cotton waste were effectively manufactured via thermally treating cotton waste in an argon environment and utilized as a tannic acid sorbent. The study by Shirvanimoghaddam et al. (2019) explained that new carbon microtubes (CMTs) generated from cotton waste were effectively manufactured via thermally treating cotton waste in an argon environment and utilized as a tannic acid (TA) sorbent. After 72 hours of sorption, the equilibrium of TA sorption was maintained which shows that sorption is a complex process. From the data analysis, the CMT9, CMT11, CMT13, and CMT15 had maximal TA sorption capacities of 465, 578, 555, and 533 mgg^{-1} respectively. The result reported are significantly higher than those previously published in the literature (Sun et al., 2017) for adsorption of TA. Fig. 14 shows the SEM image of CMT11, CMT13 and CMT15.

In another study by Mihajlović et al., (2020), waste cotton yarn was utilized as a sorbent for the separation of Cd (II), Pb (II), As (V) and Cr (III) from aqueous solution. Since heavy metal mixes are common in wastewater, competitive adsorption was studied using a mixture of selected ions. At room temperature, adsorption studies were carried out in a batch process with continual stirring. Based on the result obtained in all adsorption solutions, Pb ions had the highest removal capacity of 0.011–0.4 mg/g (90%), while As ions seemed to have the lowest affinity for the cotton yarn surface with the removal capacity of 0.002–0.075 mg/g (15%).

5. Challenges

Carbon-based materials (CBMs) from biomass waste for wastewater treatment technology has gained a lot of interest in field of science and technology over the years. It is one of the most potential materials for water purification because of its interesting properties such as interconnected porous structures, huge surface area, and macroscopic bulky structure (Wang et al., 2019). The way new products are developed has

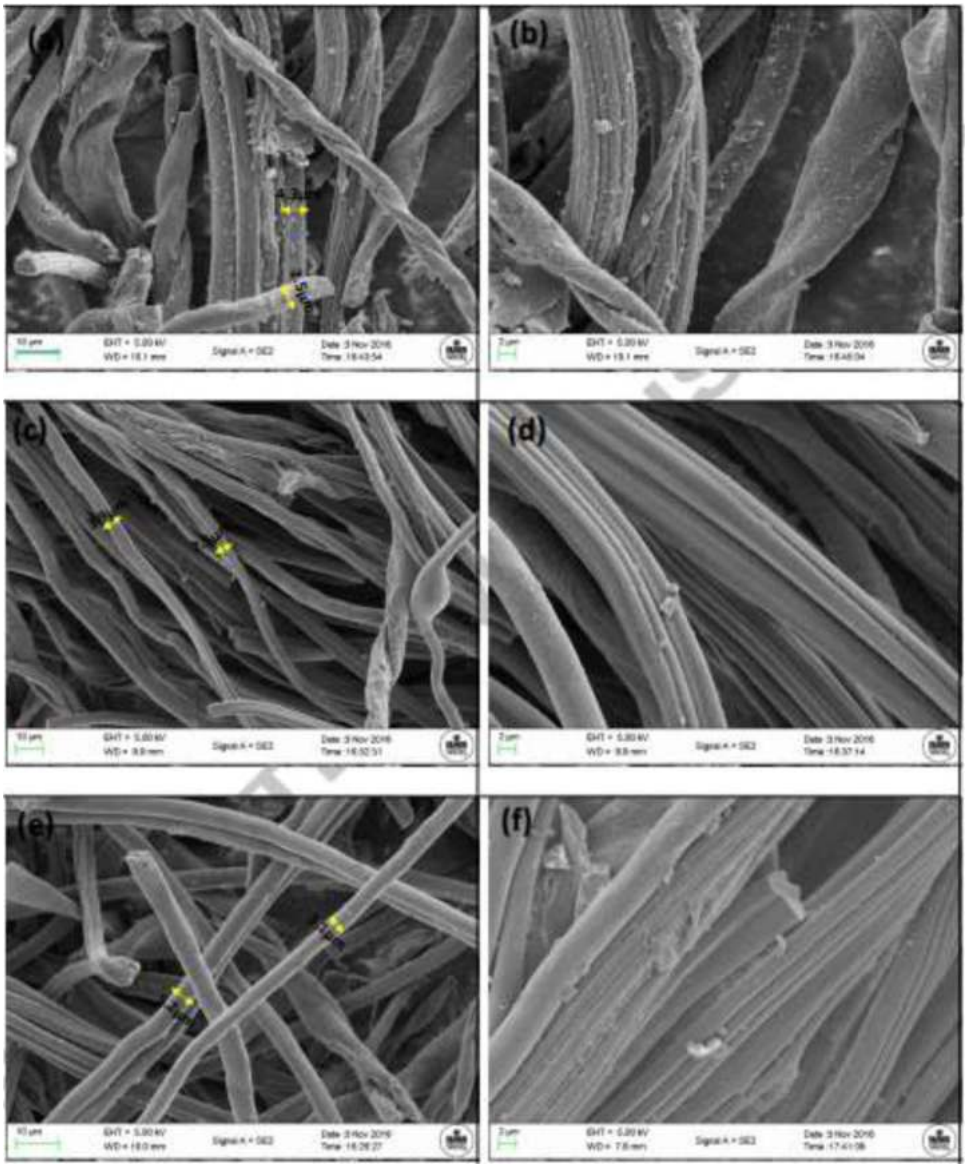

Fig. 14. SEM image of CMT samples: (a,b) CMT11;(c,d) CMT13 and (e,f) CMT15 retrieved from (Shirvanimoghaddam et al., 2019).

changed as a result of the advancement in innovation and technology.

The biggest issue in scaling up this technology is that the CBMs is not yet a fully commercial commodity (Vasileff, Zheng and Qiao, 2017). At the lab size, some pretty promising results have been shown, but scaling up is another huge challenge. This is because carbon-based compounds have only been expressed in lab-scale quantities for screening, functional, regulatory, or structural studies up to now. It can be difficult to scale up a lab-size membrane for outdoor performance testing (Dong et al., 2019). Consistency in membrane quality for large-volume processes, membrane module design and fabrication procedures, harsh operating environments with fluctuating field pollutants, and process facility requirements for offshore applications are among the challenges (Kadirkhan et al., 2019). To ensure that the membrane can be successfully applied as per the specified field specification, all scale-up issues must be meticulously addressed.

The difficulties of scaling up can be classified into different stages of development. First of all, the material screening criteria must be properly defined, including the carbon-based-materials (CBMs) for the target application, its performance, compatibility with other polymers or matrices for blending, ease of sourcing, compatibility with solvent and non-solvent for dilution and cost of screening. It is important to remember that permeability and selectivity were not the only criteria employed to create commercial membranes (Park et al., 2017). Membrane technology should have excellent processing efficacy, simple apparatus and easy integration in combination with other processing facilities to make it suitable for domestic and emergency supplies (Liu et al., 2021). Another aspect is the safety. Safety involve the risk because people are still concerning about the leaching of the carbon-based materials (CBMs) from the products.

Another aspect is the safety of using carbon-based materials (CBMs). The expaneding utilization of carbon-based materials (CBMs) requires a serious assessment of their possible effects on public health and the environment. Preliminary research into the toxicity and chemical reactivity of nanoparticles has raised major concerns, requiring the development of new, specialized disposal and recycling processes (Faunce and Kolodziejczyk, May, 2017). The presence of these compounds, particularly at trace concentration levels in the aquatic environment, has raised doubts regarding the efficacy of wastewater treatment systems in removing CBMs. Chlorination, photocatalysis, biodegradation, and advanced oxidation or ozonation have all been investigated as ways to remove CBMs from the aquatic environment. Some of these methods have disadvantages such as high costs,

significant energy consumption, and the development of toxic by-products. Nevertheless, the adsorption method has several advantages over the other techniques in term of the ability to operate in low-temperature environments, minimal energy consumption and efficiency and cost-effectiveness. Due to that, it is a potential method for removing CBMs. The Organisation for Economic Co-operation and Development (OECD), the first international bodies to acknowledge and investigate the issue of potentially hazardous nature of nanomaterials and nanowaste to environment and human health

There is a need to consider the risk that CBMs may pose to the aquatic organisms. CBMs are practically non-toxic for bacteria, whereas they are slightly toxic for crustaceans, algae and in less effect for fish. The CBMs dispersed using organic solvents showed clearly higher levels of toxicity than mechanical methods. Finally, the presence of CBMs in combination with other micro-pollutants could modify the toxic effect of each micro-pollutants, in form of synergic interactions increase of the toxic effects in presence of CBMs rather than antagonistic effects.

6. Conclusion and future outlook

Wastewater treatment from a variety of pollutants is rather a challenging task. However, carbon-based materials (CBMs) can provide both easy and efficient water purification and disinfection. This review shows that the CBMs are a new generation of pollution-control materials. These materials have the capability in adsorption and perform effectively in eliminating organics, and inorganics species due to the diversity of carbon-based structures and theirs features to form a bond with other elements through the chemical bonding forces. The highlights of this review are on CBMs like activated carbon, graphene, carbon nanotube, biochar, carbon aerogel, and porous carbon as the promising candidates to treat the wastewater from different kinds of pollutant sources. The various synthesis and modification methods as well as their conditions on the carbon-based adsorbent were discussed with the consequences for pollutant adsorption and CBMs textural properties. Despite the fact that there has been considerable discussion about CBMs, there are still obstacles to overcome in order to achieve the aim of these auspicious materials. Regardless of the fact that they made from a cheap substance, for instance, graphite, the synthesis of CBMs is still can be considered costly compared to the biomass waste application. Hence, the production of CBMs from biomass waste is a delightful idea and one step forward to lessen the cost through the green synthesis route. Overall, it may be said that the use of biomass waste can help to solve this problem while also lowering pollution. In line with this review, biomass wastes including sewage sludge, lignocellulosic, and cotton-based waste were explored for high development of CBMs and wastewater treatment.

Clearly, the interaction between the CBMs production and biomass waste utilization plays a vital role in reducing the amount of waste being thrown and discarded by the agricultural, landfill, and sewage sector into more valuable products like CBMs, where concurrently treating the water quality. The current review is expected to inspire additional future research into the derivation of CBMs from biomass waste and the application of CBMs for the adsorptive removal of widespread pollutants from wastewater. Thus, it is critical to improving the production of biomass waste-derived CBMs in order to effectively remove various contaminants. Although there are a lot of studies have been made to manufacture diverse CBMs as adsorbents, it is widely assumed that a range of deeper and extensive methodologies for carbon adsorbent synthesis and modification are still necessary especially focusing on more specific on each sort of individual biomass waste. The additional research into the possibility of carbon-based adsorbent reuse is urged since many studies concentrated on the cost-effective CBMs via biomass waste preparation. Majority of studies only investigate on CBMs in the lab, while real water encompasses a wide range of contaminants in complicated combinations, and for that reason, necessitating more knowledge in large-scale practical settings is compulsory.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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