



Article Development of Novel Microcomposite Materials from Coal Fly Ash and Incense Sticks Ash Waste and Their Application for Remediation of Malachite Green Dye from Aqueous Solutions

Virendra Kumar Yadav ¹, Bijendra Singh ², Amel Gacem ³, Krishna Kumar Yadav ⁴,*, Govindhan Gnanamoorthy ^{5,6}, Taghreed Alsufyani ⁷, Hany S. Hussein ^{8,9}, Nasser S. Awwad ¹⁰, Rajesh Verma ¹¹, Gajendra Kumar Inwati ¹², Krishna Swain ¹³ and Nisha Choudhary ¹⁴

- ¹ Department of Biosciences, School of Liberal Arts & Sciences, Mody University of Science and Technology, Sikar 332311, India
- ² School of Chemical Sciences, Central University of Gujarat, Gandhinagar 382030, India
- ³ Department of Physics, Faculty of Sciences, University 20 Août 1955, Skikda 21000, Algeria
- ⁴ Faculty of Science and Technology, Madhyanchal Professional University, Ratibad 462044, India
- ⁵ Department of Inorganic Chemistry, Guindy Campus, University of Madras, Chennai 600025, India
 - Sri Publishing Groups, Research and Development, Dharmapuri 600007, India
 - Department of Chemistry, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia
- ⁸ Electrical Engineering Department, Faculty of Engineering, King Khalid University, Abha 61411, Saudi Arabia
 - Electrical Engineering Department, Faculty of Engineering, Aswan University, Aswan 81528, Egypt
- ¹⁰ Department of Chemistry, King Khalid University, P.O. Box 9004, Abha 61413, Saudi Arabia
- Department of Electrical Engineering, College of Engineering, King Khalid University, Abha 61413, Saudi Arabia
 Department of Chemistry, Medicane University, Indexe 452221, India
 - Department of Chemistry, Medicaps University, Indore 453331, India
- ¹³ Department of Applied Mechanics, Indian Institute of Technology–Madras, Chennai 600025, India
- ¹⁴ Department of Environment Sciences, School of Sciences, P P Savani University, Surat 394125, India
 - Correspondence: envirokrishna@gmail.com

Abstract: Coal fly ash (CFA) is one of the major pollutants around the whole world. At the same time, incense stick ash (ISA) is another waste that is generated in huge amounts in Southeast Asia. Both of these wastes are rich in different types of minerals; for instance, CFA is rich in alumina, silica, and ferrous, while incense sticks ash is rich in calcium and silica. ISA has intermediate to trace amounts of ferrous, alumina, and magnesium. The addition of alkali-rich materials with high Al and Si-containing CFA helps in the formation of zeolites or geopolymers. So, in the current research work, the authors have prepared a CFA: ISA mixture in the ratio of 1:1, followed by mixing them with NaOH, CaOH₂, and KOH in a dry state in a crucible. Further, all these mixtures were then calcined at 600 °C for six hours in a muffle furnace. Further, the developed products were analyzed by various sophisticated instruments for detailed information. Finally, the developed material's potential was assessed for the remediation of malachite green from the aqueous solution by batch adsorption study. The developed adsorbents efficiently removed the dye from the aqueous solutions within one hour. The kinetic study revealed that the dye removal followed a pseudo-second-order reaction. Finally, the developed material was also assessed for its suitability as an adsorbent by observing the effect of leaching of potassium, aluminum, and silica from the adsorbent surface into the water systems. Such approaches will solve the problem of solid waste disposal arising from both the ashes.

Keywords: ferrous; alkali; calcination; silicates; alumina; adsorbent

1. Introduction

Solid waste disposal is one of the major problems of the whole world [1]. Every year, a million tonnes of solid waste are generated around the globe, especially from the agricultural domestic industries, hospitals, etc. [2]. These solid wastes are responsible for causing environmental pollution, especially in the form of land and water pollution [3].



Citation: Yadav, V.K.; Singh, B.; Gacem, A.; Yadav, K.K.; Gnanamoorthy, G.; Alsufyani, T.; Hussein, H.S.; Awwad, N.S.; Verma, R.; Inwati, G.K.; et al. Development of Novel Microcomposite Materials from Coal Fly Ash and Incense Sticks Ash Waste and Their Application for Remediation of Malachite Green Dye from Aqueous Solutions. *Water* **2022**, *14*, 3871. https://doi.org/10.3390/ w14233871 6

7

9

Academic Editors: Laura Bulgariu and Cidália Botelho

Received: 21 October 2022 Accepted: 23 November 2022 Published: 27 November 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). Most of this waste is hazardous and may be very harmful to living organisms due to the presence of toxic heavy metals and other elements [4,5]. These hazardous wastes may contaminate water and soil by leaching out heavy metals, leading to bioaccumulation which may cause various diseases [6]. Globally, a huge amount of money is spent every year by the government and non-governmental organizations (NGOs) for solid waste management [7], like coal fly ash, sanitary napkins, and red mud. These solid wastes are mainly dumped in landfills which occupy a huge amount of land area every year [8]. Out of these solid wastes, one is coal fly ash (CFA), and another one is incense stick ash (ISA) [9] which has drawn huge attention. CFA is generally produced during the generation of electricity from pulverized coal in thermal power plants (TPPs) [10–12]. CFA is glassy, micron-sized, heterogeneous spherical particles [13–15]. CFA has mainly alumina-silica and ferrous, along with several minor and trace elements like potassium, magnesium, phosphorus, sulfur, and titanium. [6,16–19]. All these elements are mainly present in the form of oxides and carbonates [20]. CFA has numerous heavy metals like arsenic, molybdenum, zinc, cadmium, chromium, nickel, mercury, and many more, which are harmful to living organisms [17,21].

ISA is another waste that is generated after the combustion of incense sticks at houses and Temples [22]. The major problem with these incense sticks is the presence of coal powder in the incense stick paste at the time of manufacturing. This powdered coal is added to the incense paste as a facilitating agent for the smoother burning of incense sticks [23]. Coal powder mixed with incense sticks paste contains all the elements present in CFA but comparatively in smaller amounts than the CFA [24]. So, like CFA, ISA also has mercury, lead, cadmium, chromium, zinc, nickel, cobalt, molybdenum, and arsenic, which are responsible for causing several diseases after bioaccumulation or biomagnification [25,26]. ISA is considered sacred in India, so it is disposed of only in rivers and other water bodies like ponds, lakes, and oceans [9,24,27,28]. These ISA, loaded with several heavy metals, may challenge a potential threat to aquatic life and human beings once they reach the water bodies. To date, very few applications of ISA are known in the scientific community [29]. Recently it has been used as an adsorbent for the removal of dyes from wastewater. Since it is rich in calcium, alumina, silica, and ferrous, several investigators have reported the recovery of all these minerals from ISA [30]. In addition to this, it also has a large amount of unburned carbon in the form of soots, carbon nanotubes, etc.

Dye effluent discharged by industries is also one of the major environmental concerns as it may pollute natural resources (land and water), leading to threats for aquatic and other living organisms, as mentioned by investigators like Yaseen and their groups [31], Maheshwari and team [32], Patel and their groups [33], and a team led by Pare [34]. So, the removal of dyes from environmental water sources is of utmost importance. However, most of the current techniques are not only inefficient but rather expensive too. Most of the adsorbents are developed from chemical precursors, whose application for environmental clean-up, like dye removal, makes it highly expensive [35]. So, the utilization of such wastebased adsorbents for dye removal, like malachite green, could be much more economical as the precursor material is a waste. The malachite green dye is used in the biological laboratory for staining purposes whose discharge into the water systems may cause a threat to aquatic animals [34,36–39].

Recently an investigation led by Yadav utilized ISA for the recovery of ferrous minerals by solid and wet magnetic separation methods. Morphologically, these ferrous particles were mainly irregular in shape. ISA was rich in carbon and calcium, along with silica, alumina, and ferrous [40]. Another investigation led by Yadav reported the synthesis of amorphous iron oxide nanoparticles (AIONPs) from the ISA-extracted ferrous particles and utilized them for the removal of dye from wastewater [25]. One more study carried out by Yadav and their team reported the recovery of ferrous, alumina, and silica from ISA with a high priority which suggested that the ISA could be used as a potential candidate in hydrometallurgy [41]. A team led by Yadav reported the synthesis of micron-sized calcium oxides and calcium carbonates in the vaterite phase. Here the synthesized vaterite phase calcium oxide was used for the remediation of methyl red dyes from the aqueous solutions with a removal percentage of up to 48% [27].

Yadav et al., 2021 reported the morphological and elemental similarities and differences between CFA and ISA. Numerous investigators reported that both the ashes have silica, alumina, and ferrous in an appreciable amount [29,42]. In addition to this, there is carbon which is also present in high quantities [43]. The only major difference between them is CFA burns at high temperatures (1200–1800 °C) while incense stick burns at low temperatures (100–150 $^{\circ}$ C), due to which most of the carbons remain unburnt. It was found that ISA has 48 to 55% calcium and magnesium oxides, whereas CFA has 5 to 15% only, silica was about 40 to 60% in CFA depending on the source and type of coal, and ISA has 5 to 20%. In CFA, alumina is about 20 to 40% based on the type or class of fly ash, i.e., class F or class C [44], whereas, in ISA, it is about 5–8% [40]. The ferrous content was about 5 to 15% in CFA, while it was about only 2 to 5% in ISA, as reported in the previous work by Yadav and their team [45]. Based on these properties of both types of ashes, it is possible to amend them, which could act as new material as an adsorbent for environmental clean-up and composite development. Moreover, the amended product could be used as a fertilizer in agriculture as a source of nutrients for plants or as a lightweight material for brick or tiles construction [46–48].

There are several reports where the surface reactivity of the waste materials like CFA, red mud, rice husk and ash [49,50], and sugarcane bagasse [51,52] were activated or increased by treatment with a strong alkali like sodium hydroxide, potassium hydroxides, and calcium hydroxides [53–56]. The alkali treatment activates the solid waste and makes them an efficient adsorbent [57] by increasing the surface reactivity. In one such attempt, Yadav et al., 2021 developed an ISA waste-derived material by mixing ISA and NaOH in a 1:1 ratio followed by calcination at 600 °C for six hours [58]. The investigator reported that the developed material from such waste was highly porous due to the presence of unbound carbon. The developed economical and ecofriendly composite material was used to remove methylene blue dye from the aqueous solutions with an efficiency rate of 70% within one hour only [58].

The main purpose for performing this research study was to develop an economical, novel composite material from waste. One further objective of this study was to develop a process for the utilization of solid waste as a value-added material. Another objective was to characterize the developed composite materials by the analytical instruments. Another objective was to remove the malachite green and other similar cationic dyes from the aqueous solutions. Assessing the leaching of elements from the surface of the adsorbents was also one of the objectives taken into consideration here. Minimization of the solid waste arising from the dumping and disposal of CFA and ISA into the fly ash ponds and water bodies was also one of the objectives. The remediation of malachite green-like cationic dye by such economical and waste material-based adsorbents could be adopted by the dye effluent industries.

In the current research work, investigators have mixed the CFA and ISA into a 1:1 ratio. These mixtures were mixed in solid form with different types of hydroxides, i.e., sodium hydroxide, potassium hydroxide, and calcium hydroxide, separately under optimized conditions. The mixtures were then sintered at 600 °C for six hours in a muffle furnace. The developed sintered composite material was analyzed by sophisticated instruments for detailed morphological elemental properties. Finally, the developed sintered products along with a mixture of ISA:CFA were used to remove malachite green dye from the aqueous solution by batch adsorption studies. The leaching behavior of Al, Si, and several other elements were also assessed for the developed adsorbent for its stability as an adsorbent.

2. Materials and Methods

2.1. Materials

Incense stick (local market), coal fly ash (collected from Gandhinagar, thermal power plant), sieves of different screen sizes (ASTM), 100 mL beaker (2–3), 100 mL round bottom

flask (2–3), Double distilled water, Magnetic retriever rod (Axiva Sichem Biotech, New Delhi, India), a Neodymium magnet (cylindrical shape procured from A-Z Magnet, Delhi, India), Sodium hydroxide pellets (Hi-media, Gujarat, India), KOH pellets (SRL, New Delhi, India), calcium hydroxides (SRL, New Delhi, India), sodium bicarbonates (Hi-media, Gujarat, India), Potassium bromide (IR, grade) (Sigma-Aldrich, Darmstadt, Germany). All the procured reagents were of analytical grade.

2.2. Methods

2.2.1. Collection and Processing of Incense Sticks Ash

Incense sticks of different brands (Moksh Agarbatti, Cycle Agarbatti, Zed Black, Nag Champa, New Delhi, India) were procured from the Uttam Nagar market area in New Delhi (India). All the packets of incense sticks were unpacked. All the incense sticks were kept on a ceramic electric coil cooking heater (ALFALITE CS-1500H 1500 WATT). These incense sticks were burned completely to obtain the ash. Once the combustion was over, the ash was collected. The collected ISA was then passed through a sieve to eliminate the unburned and large particles. The sieving was also done to eliminate the unburned bamboo sticks. The sieved ISA was stored in an air-tight glass bottle for further application.

2.2.2. Fly Ash Collection

Coal fly ash was collected from the Gandhinagar thermal power plants (located in Sector 30, Gandhinagar, Gujarat, India) in plastic silos. Fly ash was then placed in a Petri Plate and kept in a hot air oven at 70–80 °C to remove the moisture. The moisture-free fly ash was then transferred into an air-tight glass bottle for future application.

2.2.3. Preparation of ISA-CFA Alkali-Activated Sintered Product

About 8 g of CFA-ISA solid mixture was prepared in a beaker. Further, it was divided equally into three separate nickel crucibles by keeping at least two grams of sample. Further, about 2 g of NaOH, Ca(OH)₂, and KOH were added to each crucible separately. All the mixtures were mixed with the help of a separate glass rod thoroughly. Finally, the developed mixture was kept in a muffle furnace for calcination at 600 °C for six hours, where the temperature was raised gradually, i.e., 10 °C per 5 min. Finally, the samples were taken out, cooled, and converted into fine powder by using a mortar pestle. The fine powder was stored for analysis by X-ray diffraction (XRD), Fourier transforms infrared (FTIR), field emission scanning electron microscopy (FESEM), and electron diffraction spectroscopy (EDS).

A team led by Parvaiz reported the surface modification of CFA by using calcium hydroxides where a 10% wt. solution of calcium hydroxide was continuously stirred at 80–85 °C. To this solution, about 100 g of CFA was added along with stirring at 80 °C. Similarly, investigators have also prepared surface-functionalized CFA with 20 and 30% calcium hydroxide [59].

2.2.4. Dye Removal Study by Batch Adsorption Method

About one litre of 200 ppm aqueous solution of malachite green dye was prepared by dissolving the granules with the help of a magnetic stirrer. Further, about 50 mL of dye solution was taken in four separate beakers. To one of the beakers, about 0.2 mg mixture of ISA:CFA was added; to another beaker, 0.2 g of incense sticks and CFA treated with NaOH (ICNa) was added; to the third beaker, about 0.2 g of incense sticks and CFA treated with Ca(OH)₂ (IC-Ca) was added; and in the fourth beaker, about 0.2 g of incense sticks and CFA treated with Ca(OH)₂ (IC-Ca) was added; All these four beakers were kept individually on a magnetic stirring at 250 rpm at room temperature (RT). After an interval of 10 min, an aliquot of sample was collected from each beaker and was analyzed by UV-Vis spectroscopy for the measurement of malachite green dye concentration. The spectroscopic measurement of the sample was done by using a UV-Vis spectrophotometer Cary 60 UV-Vis (Agilent Technologies, Santa Clara, CA, USA).

2.2.5. Leaching of Al, Si, Mg, and Na from ICCa Adsorbent in Aqueous Solution

About 1 g of ICCa was added to 100 mL of ddw in a 250 mL beaker. The mixture was vigorously stirred on a magnetic stirrer at 250 rpm for 120 min at RT. After the completion of two hours, the mixture was centrifuged at 6000 rpm for 5 min to obtain the solid residue. The obtained residue was then transferred to a Petri Plate and dried in a hot air oven at 50 °C overnight. Finally, the dried ICCa were analyzed by FESEM for morphological changes and EDS for elemental changes.

3. Characterization of ISA and Alkali-Activated ISA Samples

3.1. FTIR Measurement

The FTIR measurement of CFA, ISA, and all the alkali-activated sintered samples was done by using Bruker Tensor 37 Bruker Corporation, (Billerica, MA, USA). The measurement was conducted in the range of 400 to 4000 cm⁻¹ at a resolution of 1 nm. For the measurement, all the samples were about 2 mg of samples, and 98 mg of KBr was taken and mixed thoroughly in a mortar pestle. Further, by using a mechanical press, a solid KBr pellet was prepared. Firstly, a blank KBr pellet was prepared, and background analysis was conducted; thereafter, all the powder samples were analyzed.

3.2. XRD Analysis

ISA, CFA, ISA:CFA, and all the alkali-activated sintered samples were analyzed by a Bruker D8 Focus instrument equipped with a 0-D detector as well as a 1-D detector. The scanning of all the samples was performed in the range of 15–60° two Theta. During this measurement, the step size was fixed at 0.02 and a time of 5 s per step at 40 kV voltage and a current of 30 mA. It was performed to find out all the mineral phases formed and dissociated after the alkali activation.

3.3. FESEM

FESEM analysis was conducted to find the morphological changes in the various alkali-activated sintered samples. For morphological analysis of the samples, both ISA and alkali-activated samples were loaded on a double-sided carbon tape, which in turn adhered to an aluminum stub. The aluminum stub, along with samples, was placed in a gold sputtering unit, and sputtering was performed for 15 min. Finally, the samples were taken out when a glow was noticed in the sputtering chamber. The samples were then placed inside the vacuum chamber of FESEM for sample analysis. The gold-coated samples were analyzed by NOVA, NanoSEM, and FEI-450 FESEM. The images of ISA:CFA and all the alkali-activated samples were taken at different magnifications to obtain detailed surface structures.

3.4. Electron Dispersive X-ray (EDX)/(EDS)

An electron beam was focused on the samples to obtain the elemental information of all the samples, and elemental data were obtained using a Bruker SDD-EDS detector attached to the FESEM.

4. Results and Discussion

4.1. FTIR for Microstructure Analysis

To explore the conformational and structural changes on the surface of the ISA, CFA, and ISA:CFA mixture and various alkali-activated sintered samples. A typical FTIR spectrum of CFA is shown in Figure 1, where there are two major bands, i.e., one at 1100 cm^{-1,} which is attributed to the $v_3 SiO_4$ stretching vibrations (Si-O-Si), while another one is at 540 cm⁻¹ which is due to Al-O, Fe-O, or Si-O-Al. Previously Yadav et al., 2022 reported a band near 565 cm⁻¹ in ISA due to the vibrational stretch mode of Fe-O [60]. The Si-O-Si indicates the presence of aluminosilicates or silicates in the CFA. The silica is mainly present in the form of a crystalline phase in the CFA. In addition to this, there is no other band in the CFA. The band at 1000 cm⁻¹ is due to the presence of a large number of silicates in

CFA, while the band near 540 cm⁻¹ is due to the metal oxides of Fe, Al, and other alkali metals. Most of the bands in the range of 500–1200 cm⁻¹ are attributed to the quartz and mullite in the CFA. Similar results were also obtained by various investigators led by Yadav et al., 2022, and Yadav and Fulekar, 2018 [5,61–63]. Kuncoro and Fahami, 2013, used CFA for the removal of lead and mercury ions from the aqueous solutions. The investigators also obtained the band in the range of 450–700 cm⁻¹, which is attributed to Al-O-Si/Al-O-Al. Investigator also obtained a band in the range of 1100–1200 cm⁻¹ attributed to the Si-O-Si (silicates).



Figure 1. FTIR spectra of CFA, ISA, ICNa, ICCa, and ICK.

In the case of ISA, there are four major bands at add 1400, 1038, 836, and 723 cm⁻¹. The band at 1400 cm⁻¹ is attributed to the carbonates [64] present in the ISA, while the band at 1038 cm⁻¹ is attributed to the v_3 SiO₄ stretching vibrations. This band is due to the presence of silica in the ISA, which comes from charcoal or coal powder. A similar type of band was also reported by investigators led by Gupta [40] and Yadav [45,65], which was attributed to the asymmetric stretching vibration of silica [40]. The band at 836 cm⁻¹ and 723 cm⁻¹ is due to the bending vibration of carbonate, which was earlier reported by a group led by Yadav 2021 [45]. Sometimes this band is also attributed to the Fe-O bond or Al-O bond in the sample since ISA has both ferrous oxides and alumina in appreciable amounts [66–68]. The results obtained here are in agreement with the results obtained by investigators led by Yadav (2001), Yadav (2022), and Jain (2020) [23,29,30,41]. The spectra show the absorption band in the range of 400–600 cm⁻¹, which is attributed to the Al-O, Al-O-Al, and Al-O-Si vibration bands of ISA [69–71].

The band near 1380 cm⁻¹ in ICK is attributed to the carbonates. Keifer et al., 2018 also reported the presence of carbonate bonds at 1388 cm⁻¹ in the water sediments [64]. In addition to this, a new band has formed at 1360 cm⁻¹, which was initially not present in the ISA sample. It also has a band at 1020 cm⁻¹, which is attributed to the v3 SiO₄ stretching vibrations bond, i.e., silicates. In addition to this, it also has a band at 723 and 547 cm⁻¹ which are attributed to the bending vibration of carbonate/metal oxide bond mainly from Fe, Al with oxygen [4]. In the case of ICNa, there is a major band at 1440, 845 and 836, and 538 cm⁻¹. The band at 1440 cm⁻¹ is attributed to the C=O of carbonates that were present in the initial sample of ISA. In addition to this, it is also attributed to the carbon bonds

present in the sample as it has a large amount of organic and inorganic carbon. A small new band has formed near 845 cm⁻¹, which was neither present in CFA nor in ISA. A new band in ICNa has formed near 538 cm⁻¹, which is attributed to the metal oxide bonds of Fe-O and Al-O [72,73].

In the case of ICCa, the prominent bands are obtained at 1440, 1038, 836, and 548 cm⁻¹. In addition to this, a new band has formed at 520 cm⁻¹, which was neither present in CFA nor ISA initially. The ICCa retained the majority of the band of ISA.

A minor sharp band is obtained at 1600 cm^{-1} in all the samples except CFA, which is attributed to the –OH group present in the water samples or from the hydroxides. Further, a small band is also noticed near 2600 cm^{-1} in all the samples except in CFA, which is attributed to the carbonates. Minor broadband is observed near $3400-3600 \text{ cm}^{-1}$ in all the samples except CFA, which is attributed to the OH group from the water molecules or hydroxides. Out of all the alkali-activated sintered samples, there is a prominent band at 3500 cm^{-1} in ICK [15,19,45,74].

4.2. XRD Analysis of Samples for Phase Identification

To identify the various minerals and their phases in the CFA, ISA, ISA:CFA, and various alkali-activated sintered samples, XRD analysis was carried out. The X-ray diffractogram is shown below in Figure 2 for all the above-mentioned samples. A sharp peak at 25–30° in ISA was attributed to silicates, mullites, and quartz structures. The silicates are mainly amorphous in nature as the incense sticks combustion is carried out at low temperatures, so the required temperature for crystallization is not achieved. A small peak at 33° is attributed to the magnetite phase present in the sample in ISA. Similar results were also reported by a group of two separate investigators led by Yadav and Jain [29,73]. Both the investigators have obtained peaks in the range of $25-28^{\circ}$ and $33-35^{\circ}$, which were attributed to quartz, silicates, and iron oxides, respectively. At the same time, the CFA has major peaks near 25 to 28° which is due to the quartz, as the majority of minerals are silica along in the form of aluminosilicates and mullites. It has a small peak near 33 to 35° which is due to magnetite and maghemite. Both CFA and ISA have a small peak from 37–42°, which is attributed to the carbonates. While the mixture of ISA:CFA has retained all the major peaks revealed by CFA and ISA individually. These peaks are due to quartz and mullite near $25-28^{\circ}$ and silicates and in ISA near 28° . At the same time, it also has iron oxide peaks and carbonates [4,26,27,29,30,40,58].

The sharp and prominent peak near 28° disappeared from ICK. Moreover, the peak near $25-28^{\circ}$ also disappears from the sample after KOH treatment and sintering. Only a small peak was present near 30 and $32-35^{\circ}$, which could be due to iron oxides. While ICCa retained the sharp peak of ISA, which is shown at 28° even after Ca(OH)₂ treatment. It has also retained the peak near $25-27^{\circ}$ from CFA, but its intensity gets reduced. In addition to this, it has a small intensity peak at 37, 40, 42, and 47° , which are attributed to carbonates. The sharp peak from ISA near 28° completely disappeared from the ICNa sample. It also does not have a peak near $25-27^{\circ}$ from CFA. In addition to this, there was the formation of several large-intensity sharp peaks from $32-37^{\circ}$, which are attributed to the iron oxides and carbonates. In addition to this, it also shows the zeolitic nature, especially Na-based zeolites, after NaOH treatment [30,75,76].

4.3. FESEM Analysis for Morphological Properties CFA-ISA

A typical FESEM micrograph of ISA is shown in Figure 3A. The particles are mainly irregular in shape due to the high amount of carbon. In addition to this, it has a few spheroid particles, which are calcium-ferro-alumino-silicates [45]. The irregular particles are highly dominant in the ISA sample. The size of the particles varied from 1 to several microns. Similar results were also reported by the team of investigators led by Yadav and Jain. At the same time, Figure 3B shows a typical FESEM image of a CFA. The CFA particle is spherically shaped in size, varying from 1–7 microns. It has well-organized spherical-

shaped particles, which have mainly ferrous, alumina, and silica along with carbon. CFA have mainly ferrous-rich ferrospheres [77–81], carbon-rich cenospheres [77,82–87], and encapsulated particles plerospheres [77]. Similar results were also obtained by teams led by Yadav in 2018 and 2021, and the size of the particles in their case was also in microns along spherical shape [88].



Figure 2. X-ray diffractogram of CFA, ISA, CFA: ISA, ICNa, ICCa, and ICK.

Figure 3D shows irregular ISA particles along with a high amount of carbon. These particles are micron-sized and appear as short rods. Similar results were also reported by Yadav et al., where ISA particles were also irregularly shaped and agglomerated, whose sizes were in the range of 100 nm to 9 microns. Moreover, the investigator reported the dominant carbon-rich particles in the samples. Figure 3E shows spherical-shaped particles where a few smaller particles get fused due to calcination temperature [58]. At the same time, Figure 3F shows ISA particles at a higher resolution where there are irregular rod-type particles along with unburned carbon particles. The EDX analysis of several ISA:CFA spots have clearly shown the presence of mainly Al, Si, Fe, Ca, C, O, Na, Mg, K, and S in Figure 3G,H. the different spots have variable compositions due to the heterogeneous nature of the mixture obtained from ISA:CFA. Carbon was present in the highest concentration in all the EDS spots, followed by oxygen. It was followed by Si, alumina, and calcium, respectively. At the same time, elements like Mg, Na, and K were also present in trace amounts.

Figure 4A–B shows FESEM micrographs at 10 and 2 microns, where several large spherical-shaped particles whose sizes vary in the range of 1–7 microns. These particles are mainly fly ash spherical particles. Some of the particles are intact, while a few have small grooves on their surface. These grooves are formed due to treatment with calcium hydroxide. In addition to this, there are small irregular-shaped particles that come from ISA, which are mainly unburned carbon and other particles. These ISA particles might not have reacted with the CFA during the reaction. From Figure 4B, it is also evident that most of the particles have white depositions, which are carbon. Figures 4C and 5D, at 1-micron resolution images, show the presence of pits on the surface of spherical particles after the

Ca(OH)₂ treatment. This treatment is formed as Si reacts with Ca(OH)₂ and forms calcium silicate. In addition to this, in Figure 4D, there are a few rod-shaped particles that could be zeolites formed after Ca(OH)₂ treatment with the mixtures of ISA:CFA. Figure 4E shows the EDS spot of the sample, while Figure 4F shows the EDS spectra and elemental table of the selected EDS spot area. Here oxygen was present in the highest concentration, followed by calcium and carbon, and others, like Si and Al, were present in traces. K and Mg were present in very small trace amounts.



Figure 3. FESEM images of an ISA: CFA mixture sample (A-F) and EDS spot (G,H).

10 of 22



Figure 4. FESEM images of ICCa product (**A**–**D**), EDS spot (**E**), and EDS spectra and elemental table (**F**), (**G**–**J**), FESEM images of ICNa product, EDS spot (**K**), and EDS spectra and elemental table (**L**). Figure 4 (**M**,**N**) is FESEM image of the ISA-NaOH sintered product adopted from [58].

In the previous sample, i.e., ISA:CFA, where carbon, Al, and Si were more, but after Ca(OH)₂ treatment, the concentration of all other elements decreased, and the concentration of Ca increased drastically. The percentage of carbon reduced several-fold while the concentration of Ca increased many-fold.

FESEM micrographs of NaOH-treated sintered particles (ICNa) are shown in Figure 4G–J. Figure 4G shows aggregates of both CFA and ISA particles. There is a complete fusion of both particles during treatment with NaOH. Figure 4H shows fused particles micron-sized having several spherical particles embedded in them. A micron-sized floral-shaped particle in Figure 4H clearly shows the formation of zeolites after treatment. In Figure 4D,I, at 100 and 200 nm, there is the presence of several small floral-shaped particles whose size is in microns. This indicates the formation of zeolites. There is the complete dissolution of the original particles which were present initially; this is so because NaOH is strong alkali. There was maximum leaching of Si and Al from the surface of particles. There are several works reported where investigators have reported the formation of zeolites from NaOH treatment by CFA and ISA separately. A team led by Yadav reported the synthesis of Ca-rich zeolites of micron-sized from ISA and sodalites [89] and faujasites [54,57,90,91] from CFA after treatment with NaOH. A group led by Yadav in 2022 developed a highly porous adsorbent by adding ISA and NaOH together in a crucible, followed by its sintering at 600 $^{\circ}$ C for 6 h in a muffle furnace. The investigators have obtained micron-sized floral-shaped particles after sintering, as shown in Figure 4M,N [92–94]. The results obtained by FESEM are also supported by the XRD data, which shows new peaks in the ICNa.



Figure 5. FESEM images of ICK product (**A**–**D**), EDS spot (**E**), and EDS spectra and elemental table (**F**).

Figure 4K shows the EDS spot of the sample, while Figure 4L is the EDS spectra and elemental table of the selected area. EDS spectra show peaks for C, O, Na, Mg, Al, Si, Ca, and K. Out of these, O was present in the highest quantity, followed by Na and carbon. The Ca and Si have almost the same concentration, i.e., 6.35 and 6.29 %, respectively. The percentage of Al was 2.93%, while Na and Mg were present in the trace amount. The concentration of carbon reduced drastically after NaOH treatment. While conc of Al, also were reduced slightly. But the conc. of all other elements increased in the sample after NaOH treatment. The concentration of Ca and Na increased drastically after the NaOH treatment; this could be because of NaOH addition and the formation of Na or Ca-based zeolites after the alkali treatment. The investigation carried out by Yadav et al. also reported the drastic increase in the Na content in the floral-shaped ISA-NaOH sintered product. The drastic increase in the Na was due to the replacement of Ca by Na ions from NaOH due to higher reactivity [58].

Figure 5A–D shows FESEM micrographs of KOH-treated CFA: ISA particles. Figure 5A–C clearly shows images of micron-sized fused particles. These are aggregates of CFA:ISA particles

that got transformed after KOH treatment. Figure 5D shows an aggregate of cuboidal-shaped particles whose size varies in the range of 80 nm to 300 nm in length and 10–40 nm in width. The image clearly indicates the transformation of the ISA:CFA particles into the zeolite. The morphology of the obtained particles is similar to the previous work reported by Yadav and their groups, where ISA was made ferrous-free and treated with dilute sulphuric acid followed by NaOH treatment. Here the final developed particles were cuboidal to rhombohedral in shape, whose size was 100–700 nm. The EDS revealed the formation of calcium-rich zeolite, i.e., gismondine [76]. There are previously several articles that clearly reported the formation of zeolites from CFA particles by using KOH.

Figure 5E shows the EDS spot of the sample, while Figure 5F shows the EDS spectra and elemental table of the sample. The EDS spectra show peaks for C, O, Al, Si, and K. Out of these elements, K is present at about 37.36% by mass, O (41.8%), C (12.12%), Si (6.3%), and Al 3.13%. In comparison to the original sample, there is a drastic decrease in the carbon content while the conc of K increased several-fold in the ICK sample. This could be due to the treatment of the sample with KOH, due to which the ISA:CFA particles were transformed into K-based zeolite particles.

5. Dye Remediation Study by the Adsorbents

About 100 ppm of an aqueous solution of malachite green dye was prepared and used for the dye removal study by the ISA:CFA and various adsorbents. The removal study was carried out at room temperature on a magnetic stirring at 350 rpm. The dose of the adsorbents, stirring speed, the temperaweree were the same for all the adsorbents. About 100 mL MG dye solution was taken in four Erlenmeyer flasks, adding about 1 mg adsorbents. An aliquot of samples was taken after every regular interval of 10 min to 60 min, and dye concentration in the samples was measured by using UV-Vis analysis (Carry 60 Agilent Technologies, Santa Clara, CA, USA).

MG Removal by ISA:CFA as an Adsorbent

The maximum absorbance peak of MG dye is mainly at 615 nm. It has been observed that the peak intensity continuously decreased till 60 min by using ISA:CFA (1:1) as an adsorbent, as shown in Figure 6a. Several investigators have used ISA and CFA separately as economical adsorbents for the remediation of various dyes from aqueous wastewater solutions. For instance, an investigation team led by Jain [29] used ISA for the removal of Victoria blue dye from wastewater. The investigators have found that the maximum uptake of Victoria dye is about 105.57 mg g⁻¹ of ISA [29]. A team led by Astuti has used CFA for the removal of methyl red dye from the aqueous solutions as a dual-site adsorbent [95].

From Figure 6b, it is clear that the concentration of the dye is continuously decreasing with respect to time by using ICNa as an adsorbent. Initially, the concentration of MGD at 0 min was the highest, and it was continuously decreasing till 60 min. After 10 to 60 min, the intensity of the dye decreased gradually and finally became colorless. Yadav and their group also reported the removal of methylene blue dye from the aqueous solutions by using an economical adsorbent developed from ISA:NaOH (1:1), followed by sintered at 600 $^{\circ}$ C. The percentage removal of MB dye was about 70% within one hour only from the aqueous solutions [73].

When ICCa was used as an adsorbent for the remediation of MGD, within 10 min, only the concentration of dye was reduced several-fold (Figure 6). After that, the concentration of dye in the solution decreased continuously till 60 min, which became colorless. A team led by Peterson showed the reactivity of coal fly ash by treating them with calcium hydroxides [72].

From the UV spectra shown in Figure 6, it is clear that the concentration of MGD is continuously decreasing from 0 min to 60 min. The concentration of dye was highest at 0 min and became colorless after 40 min only.



Figure 6. Effect of time on the concentration of malachite green dye by (**a**) ISA:CFA, (**b**) ICNa, (**c**) ICCa, and (**d**) ICK.

6. Kinetic Study of Malachite Green Removal by the Adsorbents

From the above UV-absorbance data of MGD dye removal by various adsorbents kinetic study was carried out to find the order of reaction followed during the dye removal.

Adsorption efficiency refers to the nanoadsorbent's propensity to absorb the most adsorbate possible up until equilibrium is reached; kinetics determines how long equilibrium takes to occur. To depict the phenomenon of adsorption onto adsorbent, various kinetic models can be employed. Distinctive characteristics of sorption were studied by calculating the pseudo-first order, pseudo-second order, and intraparticle diffusion models to examine the process of adsorption. A discussion was held regarding the impact of contact time on decolorization. Experimental kinetic values were applied to the pseudo-first and second-order models along with the intra-particle diffusion model to describe the process of MGD dye adsorption onto ISA:CFA, ICNa, ICCa, and ICK. The kinetic model, which is typically accurate during the initial stages of an adsorption process, indicates that the rate of change of ISA:CFA, ICNa, ICCa, and ICK uptake has a direct relationship to the change in saturation point and the quantity of solid uptake with time. According to the pseudo-second kinetic model, chemisorption will be the rate-limiting process throughout the whole adsorption range.

Figure 7a–d shows the kinetic study of MGD removal from the aqueous solution by ISA:CFA (1:1) mixture. For the first-order reaction, Qe was 25.76, K₁ was 0.159 × 10⁻⁷, and R² was 0.437. While for second order reaction, Qe was 5.69, K₂ was 0.2314, and R² was 0.998. The Intra Particle diffusion was k_{id} (mg/g·min^{3/2}) 0.6594, C (mg/g) was 1.4836, and R² was 0.7094. the values of the kinetic study are shown in Table 1 for ISA:CFA.



Figure 7. Time study (**a**,**e**,**i**,**m**) of CFA:ISA, ICNa, ICCa, and ICK, (**b**,**f**,**j**,**n**) Pseudo-first order of CFA:ISA, ICNa, ICCa, and ICK, (**c**,**g**,**k**,**o**) Pseudo second order of CFA:ISA, ICNa, ICCa, and ICK (**d**,**h**,**l**,**p**) Intra particle diffusion study of CFA:ISA, ICNa, ICCa, and ICK of Malachite green dye.

Kinetic	Parameter	Values			
		ISA:CFA	ICNa	ICCa	ICK
Pseudo-First order	$\begin{array}{c} Q_{e} \ (mg/g) \\ k_{1} \ (min^{-1}) \\ R^{2} \end{array}$	$27.56 \\ 0.159 imes 10^{-7} \\ 0.437$	$26.78 \\ 6.94 imes 10^{-7} \\ 0.285$	$26.71 \\ 0.625 \times 106 \\ 0.2449$	$\begin{array}{c} 28.1 \\ 1.80 \times 10^{-6} \\ 0.5791 \end{array}$
Pseudo-Second order	$\begin{array}{c} Q_{e} \ (mg/g) \\ k_{2} \ (g/mg \cdot min) \\ R^{2} \end{array}$	5.69 0.2314 0.998	5.68 0.125 0.994	5.56 0.194 0.9997	5.64 0.0965 0.9969
Intra Particle diffusion	$\begin{array}{c} k_{id} \ (mg/g \cdot min^{3/2}) \\ C \ (mg/g) \\ R^2 \end{array}$	0.6594 1.4836 0.7094	0.4512 2.1496 0.592	0.4306 2.2714 0.5444	0.6905 1.028 0.832

 Table 1. Kinetics Parameters of all the samples used as an adsorbent.

Figure 7e–h shows the kinetic study of MGD removal from the aqueous solution by ICNa. For the first-order reaction, Q_e was 26.78, K_1 was 6.94 $\times 10^{-7}$, and R^2 was 0.285.

While for second order reaction, Qe was 5.68, K₂ was 0.125, and R² was 0.9994. The Intra Particle diffusion was k_{id} (mg/g·min^{3/2}) 0.4512, C (mg/g) was 2.1496, and R² was 0.592.

Figure 7i–l Time study (b) Pseudo-first order (c) Pseudo-second order (d) Intra particle diffusion study of malachite green by ICNa. Figure 7m–p shows the kinetic study of MGD removal from the aqueous solution by ICCa. For the first-order reaction, Q_e was 26.71, K_1 was 0.625×10^6 , and R^2 was 0.2449. While for second order reaction, Q_e was 5.56, K_2 was 0.194, and R^2 was 0.9997. The Intra Particle diffusion was k_{id} (mg/g·min^{3/2}) 0.4306, C (mg/g) was 2.2714, and R^2 was 0.544. Table 1 shows all the kinetic parameters of the MGD dye by using ICCa.

Different kinds of the kinetic model were used for all samples to investigate the kinetic rate of the used sample toward the removal of malachite green dye from the water. The investigators have examined pseudo-first order and pseudo-second order kinetic models along with the intraparticle diffuse for the appropriate kinetic fits (Figure 7). The slopes and intercepts of the plots were used to compute the corresponding kinetic parameters such as K_1 , K_2 , and q_e . It is clearly observed that the pseudo-second-order reactions followed, and the value of the correlation coefficient (\mathbb{R}^2) was ≈ 0.9 values (Table 1), while the identical trend was not perceived for the pseudo-first-order intraparticle diffusion studies.

7. Effect on the Development as an Adsorbent for Wastewater Treatment

Figure 8A–F shows FESEM micrographs of the composite particles (ICCa) after treatment with ddw on a magnetic stirrer for 90 min. Most of the particles remained intact even after treatment which indicates that the developed composite could act as a potential candidate as an adsorbent for the remediation dyes, pesticides, and heavy metals from the wastewater or from the aqueous solutions.

The intact spherical shape of the developed composite confirms that the material does not get affected by water treatment at RT. The EDS spot and EDS spectra of (ICK) developed particles after treatment with water are shown in Figure 8G,H EDS analysis was done to find the changes in the various element concentrations during treatment with water as an adsorbent. A better adsorbent is one that does not leach out elements from them into the water systems during the adsorption process. The silica content decreased significantly in the final residual samples, as evidenced by EDS. EDS spectra show peaks for C, O, Si, Al, K, Ca, and K. All these were present in the adsorbent before being treated with water. While the EDS table shows the concentration of elements, i.e., C is present in the highest amount followed by O. Except these two rests are present in trace amounts in the material. In comparison to the ISK and ISK after treatment with water, it was observed that the percentage of carbon increased drastically in the water-treated samples. The increase in the C was almost six-fold. In addition to this, after treatment with water, the percentage of Si and Al decreased many-fold. In the initial adsorbent sample, the percentage of Al was 3.13 wt.%, while in the water-treated adsorbent, Al was 0.8 wt.%. So, the decrease in the Al was about four-fold. Similarly, Si was initially 6.2 wt.% whereas, after water treatment, it reduced to 1.47 wt.%, i.e., the reduction was more than four-fold. Similarly, O concentration also decreased after treatment with water. The reduction in O was about 1.3-fold. Initially, calcium was not detected, but in the water-treated sample, it was present on the surface of ICK. Similarly, in the initial sample, K was about 37.36 wt.%, while in the water-treated sample, it was only 0.69 wt.%. This indicates the drastic reduction of K after water treatment. Moreover, the water-treated ICK EDS profile (Figure 8G,H) reveals that there is leaching of Si, Al, and K from the ICK in the water sample at room temperature. Silica is generally acid-insoluble but easily dissolves in strong bases. At the same time, aluminum is amphoteric in nature, i.e., both acid as well as base soluble. At the same time, potassium is water soluble in normal water at room temperature. So, there is the possibility that there was a leaching of K⁺ ions from the ICK, which might have formed KOH along with the OH group of water. Further, the basic condition in the aqueous system might have dissolved Si and Al from the surface of the ICK. So, both of these elements might be present in the leachate obtained after treatment. Moreover, the leachate could have potential in the

metallurgy for the recovery of Si and Al metals. Moreover, it was found that ISK, when used as an adsorbent in the water systems, even at room temperature, might be leaching a few elements, so it could not be a suitable candidate as an adsorbent.



Figure 8. FESEM images of ICCa residual product after treatment with distilled water (A–F), EDS spot, and elemental table (G,H) water treated residual sample.

Adsorption Mechanism of Malachite Green by Adsorbents

Figure 9 shows a possible mechanism for the uptake of MG dye on the surface of the adsorbent based on the results of modeling studies. Various studies have shown that the dyes are being taken up from the aqueous solution by the adsorbents due to chemisorption and physisorption processes. The presence of various functional groups on the surface of the adsorbents has been revealed by the FTIR. Moreover, the porous nature was also evident from the FESEM micrographs of the adsorbents. The presence of functional groups on these adsorbents could vary based on the pH, temperature, etc., of the reaction conditions. MG is a cationic dye whose pKa value is 6.9. The pH of the reaction medium was near neutrality (6.7). At high pH, the MG remains unionized in the solutions. Most of the adsorbents have –OH groups on their surface due to the presence of hydrates in the structure, so this cationic dye is attracted to the surface of the adsorbents due to –OH groups. Being cationic in nature, MG dye interacts with the negatively charged adsorbents via electrostatic attraction. In addition to this, there are several forces, for instance, pi–pi interactions between the functional groups of the adsorbents and the MG dye molecule. In addition to this, there are electrostatic interactions like London dispersion interactions, Vander wall forces, and

dipole-induced dipole bonds. Several investigators have also reported similar uptake of dyes, including MG, from the aqueous solutions. For instance, Igwegbe, 2021 and Balrack 2021 predicated similar types of possible adsorption mechanism dyes like Congo red, malachite green, acid orange 7, and AB92 [96,97]. A more recent attempt by a team led by Igwegbe 2021 reported the remediation of Congo red and malachite green dye from the aqueous solutions. In this approach, Igwegbe et al. showed that the biosorbents developed from rubber seed shells (*Hevea brasiliensis*) have the potential for the efficient removal of MG dye by similar adsorption mechanisms. The investigators also reported the uptake of MG on the adsorbent surface due to electrostatic interaction (London dispersion interactions, Vander wall forces, and dipole-induced dipole bonds), intraparticle pore diffusion, and pi–pi interactions [39].



Figure 9. Summary of possible adsorption mechanism of malachite green dye by the adsorbents.

8. Conclusions

Both CFA and incense stick ash are waste but rich in several value-added elements, which could prove to be valuable in metallurgy. The CFA rich in aluminosilicates and ISA rich in calcium oxides could together act as a new resource material in material science. The treatment of CFA and incense stick ash by alkali and their subsequent analysis showed the potential application of the developed material in metallurgy and environmental clean-up. Ca(OH)₂, being a weak alkali, could not transform the fly ash and incense sticks ash particles into zeolites rather only leached Si and other elements from the surface and showed small grooves on the external surface. While NaOH, being a strong alkali, reacted with the ash particles and transformed them into Na-based floral-shaped zeolites. While the KOH also transformed the ash particles into Ca-rich cuboidal-shaped zeolites. The developed composites were micron-sized, irregular to floral shaped, as shown by FESEM. The XRD and FTIR show that the developed composite materials' features are close to zeolites. All the developed adsorbents from the fusion of the two wastes showed efficient removal of malachite green within 40–120 min. Moreover, the dye was completely decolorized with the dew of the adsorbents within a very short period of time. The kinetic study of malachite

green removal from the aqueous solutions revealed the pseudo-second-order reaction. The synthesis of such economical value-added material from waste particles minimizes solid waste, which generally pollutes the water bodies. There is also a possibility of utilization of such waste in material science and metallurgy.

Author Contributions: Conceptualization, N.C., K.S., T.A., B.S. and N.S.A.; Data curation, V.K.Y., B.S., N.C. and R.V.; methodology, G.G., V.K.Y. and A.G.; validation, K.K.Y., G.K.I. and K.S.; formal analysis, G.K.I. and H.S.H.; resources, K.K.Y., K.S., N.S.A. and N.C.; writing—original draft preparation, V.K.Y., G.K.I., B.S. and N.C.; writing—review and editing, B.S., A.G., V.K.Y., G.G., K.K.Y., G.K.I., H.S.H. and T.A.; supervision, K.S., V.K.Y., T.A. and R.V.; project administration V.K.Y., R.V., N.S.A. and K.K.Y.; Funding acquisition, R.V., H.S.H. and A.G.; Investigation, V.K.Y., N.C. and G.G.; Software's, T.A., N.S.A., R.V. and K.K.Y.; Visualization, A.G., H.S.H. and G.G. All authors have read and agreed to the published version of the manuscript.

Funding: The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for supporting this work through the Large Groups Project under Grant number (RGP.2/16/43). The authors gratefully acknowledge Taif University Researchers Supporting Project, number (TURSP-2020/242), Taif University, Taif, Saudi Arabia.

Data Availability Statement: Not Applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

- 1. Debnath, N.K.; Acharya, V.; Jangu, S.; Singh, P.; Majhi, M.R.; Singh, V.K. Characterization of fly ash solid-waste for low-cost insulation refractory bricks. *Mater. Today Proc.* 2021, 47, 1598–1600. [CrossRef]
- Malav, L.C.; Yadav, K.K.; Gupta, N.; Kumar, S.; Sharma, G.K.; Krishnan, S.; Rezania, S.; Kamyab, H.; Pham, Q.B.; Yadav, S.; et al. A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities. J. Clean Prod. 2020, 277, 123227. [CrossRef]
- Alharthi, M.; Hanif, I.; Alamoudi, H. Impact of environmental pollution on human health and financial status of households in MENA countries: Future of using renewable energy to eliminate the environmental pollution. *Renew. Energy* 2022, 190, 338–346.
 [CrossRef]
- Yadav, V.K.; Yadav, K.K.; Alam, J.; Cabral-Pinto, M.; Gnanamoorthy, G.; Alhoshan, M.; Kamyab, H.; Hamid, A.A.; Ali, F.A.A.; Shukla, A.K. Transformation of hazardous sacred incense sticks ash waste into less toxic product by sequential approach prior to their disposal into the water bodies. *Environ. Sci. Pollut. Res.* 2021, 1–13. [CrossRef]
- 5. Rafieizonooz, M.; Khankhaje, E.; Rezania, S. Assessment of environmental and chemical properties of coal ashes including fly ash and bottom ash, and coal ash concrete. *J. Build. Eng.* **2022**, *49*, 104040. [CrossRef]
- Kozáková, Ľ.; Bakalár, T.; Zeleňák, M.; Praščáková, M. Solidification of MSWI fly-ash with regard to hazardous metals leaching. Acta Montan. Slovaca 2013, 18, 129–139.
- Sun, X.; Li, J.; Zhao, X.; Zhu, B.; Zhang, G. A Review on the Management of Municipal Solid Waste Fly Ash in American. Procedia Environ. Sci. 2016, 31, 535–540. [CrossRef]
- Roy, D.; Tarafdar, A. Solid Waste Management and Landfill in High-Income Countries. In *Circular Economy in Municipal Solid* Waste Landfilling: Biomining & Leachate Treatment: Sustainable Solid Waste Management: Waste to Wealth; Pathak, P., Palani, S.G., Eds.; Springer International Publishing: Cham, Switzerland, 2022; pp. 1–23. [CrossRef]
- Yadav, V.K.; Kumar, P.; Kalasariya, H.; Choudhary, N.; Singh, B.; Gnanamoorthy, G.; Gupta, N.; Khan, S.H.; Khayal, A. The current scenario of Indian incense sticks market and their impact on the Indian economy. *Ind. J. Pure Appl. Biosci.* 2020, *8*, 627–636. [CrossRef]
- Adewuyi, Y.G. Recent Advances in Fly-Ash-Based Geopolymers: Potential on the Utilization for Sustainable Environmental Remediation. ACS Omega 2021, 6, 15532–15542. [CrossRef]
- 11. Khan, M.A.; Memon, S.A.; Farooq, F.; Javed, M.F.; Aslam, F.; Alyousef, R. Compressive Strength of Fly-Ash-Based Geopolymer Concrete by Gene Expression Programming and Random Forest. *Adv. Civ. Eng.* **2021**, 2021, 6618407. [CrossRef]
- 12. Hwang, S.; Yeon, J.H. Fly Ash-Added, Seawater-Mixed Pervious Concrete: Compressive Strength, Permeability, and Phosphorus Removal. *Materials* **2022**, *15*, 1407. [CrossRef] [PubMed]
- Yadav, V.K.; Suriyaprabha, R.; Inwati, G.K.; Gupta, N.; Singh, B.; Lal, C.; Kumar, P.; Godha, M.; Kalasariya, H. A Noble and Economical Method for the Synthesis of Low Cost Zeolites From Coal Fly Ash Waste. *Adv. Mater. Process. Technol.* 2021, 1–19. [CrossRef]
- Yatsenko, E.A.; Goltsman, B.M.; Trofimov, S.V.; Kurdashov, V.M.; Novikov, Y.V.; Smoliy, V.A.; Ryabova, A.V.; Klimova, L.V. Improving the Properties of Porous Geopolymers Based on TPP Ash and Slag Waste by Adjusting Their Chemical Composition. *Materials* 2022, 15, 2587. [CrossRef] [PubMed]

- Chen, H.; Khalili, N. Fly-Ash-Modified Calcium-Based Sorbents Tailored to CO₂ Capture. *Ind. Eng. Chem. Res.* 2017, 56, 1888–1894.
 [CrossRef]
- Yadav, V.K.; Yadav, K.K.; Tirth, V.; Jangid, A.; Gnanamoorthy, G.; Choudhary, N.; Islam, S.; Gupta, N.; Son, C.T.; Jeon, B.H. Recent advances in methods for recovery of cenospheres from fly ash and their emerging applications in ceramics, composites, polymers and environmental cleanup. *Crystals* 2021, *11*, 1067. [CrossRef]
- Kumar, P.; Singh, N. Influence of recycled concrete aggregates and Coal Bottom Ash on various properties of high volume fly ash-self compacting concrete. J. Build. Eng. 2020, 32, 101491. [CrossRef]
- Iyer, R.S.; Scott, J.A. Power station fly ash—A review of value-added utilization outside of the construction industry. *Resour. Conserv. Recycl.* 2001, 31, 217–228. [CrossRef]
- Ściubidło, A.; Majchrzak-Kucęba, I. Exhaust gas purification process using fly ash-based sorbents. *Fuel* 2019, 258, 116126. [CrossRef]
- Gadore, V.; Ahmaruzzaman, M.D. Fly ash-based nanocomposites: A potential material for effective photocatalytic degradation/elimination of emerging organic pollutants from aqueous stream. *Environ. Sci. Pollut. Res.* 2021, 28, 46910–46933. [CrossRef]
- Yadav, V.K.; Inwati, G.K.; Ali, D.; Gnanamoorthy, G.; Bera, S.P.; Khan, S.H.; Choudhary, N.; Kumar, G.; Chaurasia, T.P.; Basnet, A. Remediation of Azure A Dye from Aqueous Solution by Using Surface-Modified Coal Fly Ash Extracted Ferrospheres by Mineral Acids and Toxicity Assessment. *Adsorpt. Sci. Technol.* 2022, 2022, 7012889. [CrossRef]
- Yadav, V.K.; Malik, P.; Tirth, V.; Khan, S.H.; Yadav, K.K.; Islam, S.; Choudhary, N.; Inwati, G.K.; Arabi, A.; Kim, D.-H. Health and Environmental Risks of Incense Smoke: Mechanistic Insights and Cumulative Evidence. J. Inflamm. Res. 2022, 15, 2665. [CrossRef] [PubMed]
- 23. Yadav, V.K.; Singh, B.; Choudhary, N. Characterization of Indian incense stick powders for their physical, chemical and mineralogical properties. *World J. Environ. Biosci.* 2020, *9*, 39–43.
- Yadav, V.K.; Choudhary, N.; Heena Khan, S.; Khayal, A.; Ravi, R.K.; Kumar, P.; Modi, S.; Gnanamoorthy, G. Incense and Incense Sticks: Types, Components, Origin and Their Religious Beliefs and Importance among Different Religions. *J. Bio. Innov.* 2020, 9, 1420–1439. [CrossRef]
- Yadav, V.K.; Yadav, K.K.; Gnanamoorthy, G.; Choudhary, N.; Khan, S.H.; Gupta, N.; Kamyab, H.; Bach, Q.-V. A novel synthesis and characterization of polyhedral shaped amorphous iron oxide nanoparticles from incense sticks ash waste. *Environ. Technol. Innov.* 2020, 20, 101089. [CrossRef]
- Yadav, V.K.; Gnanamoorthy, G.; Ali, D.; Bera, S.P.; Roy, A.; Kumar, G.; Choudhary, N.; Kalasariya, H.; Basnet, A. Cytotoxicity, Removal of Congo Red Dye in Aqueous Solution Using Synthesized Amorphous Iron Oxide Nanoparticles from Incense Sticks Ash Waste. J. Nanomater. 2022, 2022, 1–12. [CrossRef]
- Yadav, V.K.; Yadav, K.K.; Gacem, A.; Gnanamoorthy, G.; Ali, I.H.; Khan, S.H.; Jeon, B.-H.; Kamyab, H.; Inwati, G.K.; Choudhary, N. A novel approach for the synthesis of vaterite and calcite from incense sticks ash waste and their potential for remediation of dyes from aqueous solution. *Sustain. Chem. Pharm.* 2022, 29, 100756. [CrossRef]
- Šulc, R.; Šídlová, M.; Formáček, P.; Snop, R.; Škvára, F.; Polonská, A. A Study of Physicochemical Properties of Stockpile and Ponded Coal Ash. *Materials* 2022, 15, 3653. [CrossRef]
- 29. Jain, S.N.; Tamboli, S.R.; Sutar, D.S.; Mawal, V.N.; Shaikh, A.A.; Prajapati, A.A. Incense stick ash as a novel and sustainable adsorbent for sequestration of Victoria Blue from aqueous phase. *Sustain. Chem. Pharm.* **2020**, *15*, 100199. [CrossRef]
- Yadav, V.K.; Choudhary, N.; Tirth, V.; Kalasariya, H.; Gnanamoorthy, G.; Algahtani, A.; Yadav, K.K.; Soni, S.; Islam, S.; Yadav, S. A short review on the utilization of incense sticks ash as an emerging and overlooked material for the synthesis of zeolites. *Crystals* 2021, 11, 1255. [CrossRef]
- Yaseen, D.A.; Scholz, M. Textile dye wastewater characteristics and constituents of synthetic effluents: A critical review. *Int. J. Environ. Sci. Technol.* 2019, 16, 1193–1226. [CrossRef]
- 32. Maheshwari, K.; Agrawal, M.; Gupta, A.B. Dye Pollution in Water and Wastewater. In *Novel Materials for Dye-Containing Wastewater Treatment*; Muthu, S.S., Khadir, A., Eds.; Springer: Singapore, 2021; pp. 1–25. [CrossRef]
- Patel, H.; Yadav, V.K.; Yadav, K.K.; Choudhary, N.; Kalasariya, H.; Alam, M.M.; Gacem, A.; Amanullah, M.; Ibrahium, H.A.; Park, J.-W.; et al. A Recent and Systemic Approach towards Microbial Biodegradation of Dyes from Textile Industries. *Water* 2022, 14, 3163. [CrossRef]
- Pare, B.; Barde, V.S.; Solanki, V.S.; Agarwal, N.; Yadav, V.K.; Alam, M.M.; Gacem, A.; Alsufyani, T.; Khedher, N.; Park, J.W.; et al. Green Synthesis and Characterization of LED-Irradiation-Responsive Nano ZnO Catalyst and Photocatalytic Mineralization of Malachite Green Dye. *Water* 2022, 14, 3221. [CrossRef]
- Patel, Y.; Chhaya, U.; Rudakiya, D.M.; Joshi, S. Biological Decolorization and Degradation of Synthetic Dyes: A Green Step Toward Sustainable Environment. In *Microbial Rejuvenation of Polluted Environment*; Panpatte, D.G., Jhala, Y.K., Eds.; Springer: Singapore, 2021; Volume 2, pp. 77–110. [CrossRef]
- Gnanamoorthy, G.; Yadav, V.K.; Ali, D.; Ramar, K.; Ali, H.; Narayanan, V. New designing (NH4) 2SiP4O13 nanowires and effective photocatalytic degradation of Malachite Green. *Chem. Phys. Lett.* 2022, 803, 139817. [CrossRef]
- 37. Argumedo-Delira, R.; Gómez-Martínez, M.J.; Uribe-Kaffure, R. Trichoderma biomass as an alternative for removal of congo red and malachite green industrial dyes. *Appl. Sci.* 2021, *11*, 448. [CrossRef]

- Caponi, N.; Collazzo, G.C.; Jahn, S.L.; Dotto, G.L.; Mazutti, M.A.; Foletto, E.L. Use of Brazilian kaolin as a potential low-cost adsorbent for the removal of malachite green from colored effluents. *Mater. Res.* 2017, 20, 14–22. [CrossRef]
- Igwegbe, C.A.; Ighalo, J.O.; Onyechi, K.K.; Onukwuli, O.D. Adsorption of Congo red and malachite green using H₃PO₄ and NaCl-modified activated carbon from rubber (*Hevea brasiliensis*) seed shells. *Sustain. Water Resour. Manag.* 2021, 7, 63. [CrossRef]
- Gupta, N.; Yadav, V.K.; Yadav, K.K.; Alwetaishi, M.; Gnanamoorthy, G.; Singh, B.; Jeon, B.-H.; Cabral-Pinto, M.M.S.; Choudhary, N.; Ali, D. Recovery of iron nanominerals from sacred incense sticks ash waste collected from temples by wet and dry magnetic separation method. *Environ. Technol. Innov.* 2022, 25, 102150. [CrossRef]
- Yadav, V.K.; Gnanamoorthy, G.; Yadav, K.K.; Ali, I.H.; Bagabas, A.A.; Choudhary, N.; Yadav, S.; Suriyaprabha, R.; Islam, S.; Modi, S. Utilization of Incense Stick Ash in Hydrometallurgy Methods for Extracting Oxides of Fe, Al, Si, and Ca. *Materials* 2022, 15, 1879. [CrossRef]
- 42. Singh, D.; Yadav, V.K.; Ali, D.; Soni, S.; Kumar, G.; Dawane, V.; Chaurasia, T.P. Isolation and Characterization of Siderophores Producing Chemolithotrophic Bacteria from the Coal Samples of the Aluminum Industry. *Geomicrobiol. J.* **2022**, 1–7. [CrossRef]
- Li, Y.J.; Yeung, J.W.T.; Leung, T.P.I.; Lau, A.P.S.; Chan, C.K. Characterization of organic particles from incense burning using an aerodyne high-resolution time-of-flight aerosol mass spectrometer. *Aerosol Sci. Technol.* 2012, 46, 654–665. [CrossRef]
- 44. Chancey, R.T.; Stutzman, P.; Juenger, M.C.G.; Fowler, D.W. Comprehensive phase characterization of crystalline and amorphous phases of a Class F fly ash. *Cem. Concr. Res.* **2010**, *40*, 146–156. [CrossRef]
- 45. Yadav, V.K.; Gnanamoorthy, G.; Cabral-Pinto, M.M.S.; Alam, J.; Ahamed, M.; Gupta, N.; Singh, B.; Choudhary, N.; Inwati, G.K.; Yadav, K.K. Variations and similarities in structural, chemical, and elemental properties on the ashes derived from the coal due to their combustion in open and controlled manner. *Environ. Sci. Pollut. Res.* 2021, 28, 32609–32625. [CrossRef] [PubMed]
- 46. Balapour, M.; Khaneghahi, M.H.; Garboczi, E.J.; Hsuan, Y.G.; Hun, D.E.; Farnam, Y. Off-spec fly ash-based lightweight aggregate properties and their influence on the fresh, mechanical, and hydration properties of lightweight concrete: A comparative study. *Constr. Build. Mater.* **2022**, *342*, 128013. [CrossRef]
- 47. Balapour, M.; Thway, T.; Rao, R.; Moser, N.; Garboczi, E.J.; Hsuan, Y.G.; Farnam, Y. A thermodynamics-guided framework to design lightweight aggregate from waste coal combustion fly ash. *Resour. Conserv. Recycl.* 2022, 178, 106050. [CrossRef]
- Wen, S.; Buyukada, M.; Evrendilek, F.; Liu, J. Uncertainty and sensitivity analyses of co-combustion/pyrolysis of textile dyeing sludge and incense sticks: Regression and machine-learning models. *Renew. Energy* 2020, 151, 463–474. [CrossRef]
- 49. Hoang, N.; Ngoc, L. Characterization of Geopolymer-based Materials Synthesized from Fly Ash and Rice Husk Ash. Available Online WwwJsaerCom. *J. Sci. Eng. Res.* **2018**, 270, 270–277.
- 50. Lo, F.-C.; Lee, M.-G.; Lo, S.L. Effect of coal ash and rice husk ash partial replacement in ordinary Portland cement on pervious concrete. *Constr. Build. Mater.* **2021**, *286*, 122947. [CrossRef]
- 51. Gupta, V.K.; Sharma, S. Removal of Zinc from Aqueous Solutions Using Bagasse Fly Ash—A Low Cost Adsorbent. *Ind. Eng. Chem. Res.* 2003, 42, 6619–6624. [CrossRef]
- 52. Patil, C.; Manjunath, M.; Hosamane, S.; Bandekar, S.; Athani, R. Pozzolonic activity and strength activity index of bagasse ash and fly ash blended cement mortar. *Mater. Today Proc.* 2021, 42, 1456–1461. [CrossRef]
- Murukutti, M.K.; Jena, H. Synthesis of nano-crystalline zeolite-A and zeolite-X from Indian coal fly ash, its characterization and performance evaluation for the removal of Cs+ and Sr2+ from simulated nuclear waste. J. Hazardous Mater. 2022, 423, 127085. [CrossRef]
- Li, L.; Wei, X.-Y.; Liu, G.-H.; Li, Z.; Li, J.-H.; Liu, F.-J.; Kong, Q.-Q.; Fan, Z.-C.; Zong, Z.-M.; Bai, H.-C. Selective catalytic hydroconversion of organic waster oil to cyclanes over a coal fly ash-derived zeolite-supported nickel catalyst: Waster to energy. *Fuel* 2022, *316*, 123185. [CrossRef]
- 55. Roulia, M.; Koukouza, K.; Stamatakis, M.; Vasilatos, C. Fly-ash derived Na-P1, natural zeolite tuffs and diatomite in motor oil retention. *Clean. Mater.* 2022, *4*, 100063. [CrossRef]
- Inada, M.; Eguchi, Y.; Enomoto, N.; Hojo, J. Synthesis of zeolite from coal fly ashes with different silica–alumina composition. *Fuel* 2004, *84*, 299–304. [CrossRef]
- Lim, J.M.; Park, J.; Park, J.T.; Bae, S. Preparation of quasi-solid-state electrolytes using a coal fly ash derived zeolite-X and -A for dye-sensitized solar cells. J. Ind. Eng. Chem. 2019, 71, 378–386. [CrossRef]
- Yadav, V.K.; Choudhary, N.; Ali, D.; Kumar, G.; Gnanamoorthy, G.; Khan, A.U.; Kumar, P.; Hari Kumar, S.; Tizazu, B.Z. Determination of Adsorption of Methylene Blue Dye by Incense Stick Ash Waste and Its Toxicity on RTG-2 Cells. *Adsorpt. Sci. Technol.* 2022, 2022, 1–10. [CrossRef]
- 59. Parvaiz, M.R.; Mohanty, S.; Nayak, S.K.; Mahanwar, P.A. Effect of surface modification of fly ash on the mechanical, thermal, electrical and morphological properties of polyetheretherketone composites. *Mater. Sci. Eng. A* 2011, 528, 4277–4286. [CrossRef]
- 60. Du, X.; Huang, Z.; Ding, Y.; Xu, W.; Zhang, M.; Wei, L.; Yang, H. Feasibility Study of Grinding Circulating Fluidized Bed Ash as Cement Admixture. *Materials* **2022**, *15*, 5610. [CrossRef]
- 61. Yadav, V.K.; Fulekar, M.H. Advances in methods for recovery of ferrous, alumina, and silica nanoparticles from fly ash waste. *Ceramics* **2020**, *3*, 384–420. [CrossRef]
- Yadav, V.K.; Fulekar, M.H. Green synthesis and characterization of amorphous silica nanoparticles from fly ash. *Mater. Today Proc.* 2019, 18, 4351–4359. [CrossRef]
- 63. Yadav, V.K.; Saxena, P.; Lal, C.; Gnanamoorthy, G.; Choudhary, N.; Singh, B.; Tavker, N.; Kalasariya, H.; Kumar, P. Synthesis and Characterization of Mullites From Silicoaluminous Fly Ash Waste. *Int. J. Appl. Nanotechnol. Res.* **2020**, *5*, 10–25. [CrossRef]

- 64. Kiefer, J.; Stärk, A.; Kiefer, A.L.; Glade, H. Infrared Spectroscopic Analysis of the Inorganic Deposits from Water in Domestic and Technical Heat Exchangers. *Energies* **2018**, *11*, 798. [CrossRef]
- Yadav, V.K.; Gacem, A.; Choudhary, N.; Rai, A.; Kumar, P.; Yadav, K.K.; Abbas, M.; Khedher, N.B.; Awwad, N.S.; Barik, D.; et al. Status of Coal-Based Thermal Power Plants, Coal Fly Ash Production, Utilization in India and Their Emerging Applications. *Minerals* 2022, 12, 1503. [CrossRef]
- See, S.W.; Balasubramanian, R.; Man Joshi, U. Physical characteristics of nanoparticles emitted from incense smoke. *Sci. Technol. Adv. Mater.* 2007, *8*, 25–32. [CrossRef]
- Lin, T.-C.; Krishnaswamy, G.; Chi, D.S. Incense smoke: Clinical, structural and molecular effects on airway disease. *Clin. Mol. Allergy* 2008, *6*, 3. [CrossRef] [PubMed]
- Jilla, A.; Kura, B. Particulate Matter and Carbon Monoxide Emission Factors from Incense Burning. *Environ. Pollut. Clim. Change* 2017, 1, 1–7. [CrossRef]
- Goel, A.; Wathore, R.; Chakraborty, T.; Agrawal, M. Characteristics of exposure to particles due to incense burning inside temples in Kanpur, India. *Aerosol Air Qual. Res.* 2017, 17, 608–615. [CrossRef]
- Lee, S.C.; Wang, B. Characteristics of emissions of air pollutants from burning of incense in a large environmental chamber. *Atmos. Environ.* 2004, *38*, 941–951. [CrossRef]
- Wen, S.; Yan, Y.; Liu, J.; Buyukada, M.; Evrendilek, F. Pyrolysis performance, kinetic, thermodynamic, product and joint optimization analyses of incense sticks in N₂ and CO₂ atmospheres. *Renew. Energy* 2019, 141, 814–827. [CrossRef]
- 72. Peterson, J.R.; Rochelle, G.T. Aqueous reaction of fly ash and calcium hydroxide to produce calcium silicate absorbent for flue gas desulfurization. *Environ. Sci. Technol.* **1988**, *22*, 1299–1304. [CrossRef]
- 73. Gupta, N.; Yadav, V.K.; Gacem, A.; Al-Dossari, M.; Yadav, K.K.; Abd El-Gawaad, N.S.; Ben Khedher, N.; Choudhary, N.; Kumar, P.; Cavalu, S. Deleterious Effect of Air Pollution on Human Microbial Community and Bacterial Flora: A Short Review. Int. J. Environ. Res. Public Health 2022, 19, 15494. [CrossRef]
- Das, D.; Rout, P.K. Synthesis, Characterization and Properties of Fly Ash Based Geopolymer Materials. *J. Mater. Eng. Perform.* 2021, 30, 3213–3231. [CrossRef]
- Miricioiu, M.G.; Niculescu, V.-C. Fly Ash, from Recycling to Potential Raw Material for Mesoporous Silica Synthesis. *Nanomaterials* 2020, 10, 474. [CrossRef] [PubMed]
- 76. Yadav, V.K.; Choudhary, N.; Ali, D.; Gnanamoorthy, G.; Inwati, G.K.; Almarzoug, M.H.A.; Kumar, G.; Khan, S.H.; Solanki, M.B. Experimental and computational approaches for the structural study of novel Ca-rich zeolites from incense stick ash and their application for wastewater treatment. *Adsorpt. Sci. Technol.* 2021, 2021, 1–12. [CrossRef]
- 77. Choudhary, N.; Yadav, V.K.; Malik, P.; Khan, S.H.; Inwati, G.K.; Suriyaprabha, R.; Singh, B.; Yadav, A.K.; Ravi, R.K. Recovery of natural nanostructured minerals: Ferrospheres, plerospheres, cenospheres, and carbonaceous particles from fly ash. In *Handbook of Research on Emerging Developments and Environmental Impacts of Ecological Chemistry*; IGI Global: Hershey, PA, USA, 2020; pp. 450–470.
- 78. Sunjidmaa, D.; Batdemberel, G.; Takibai, S. A Study of Ferrospheres in the Coal Fly Ash. *Open J. Appl. Sci.* **2019**, *9*, 10–16. [CrossRef]
- 79. Sharonova, O.M.; Anshits, N.N.; Fedorchak, M.A.; Zhizhaev, A.M.; Anshits, A.G. Characterization of Ferrospheres Recovered from High-Calcium Fly Ash. *Energy Fuels* **2015**, *29*, 5404–5414. [CrossRef]
- Xue, Q.F.; Lu, S.G. Microstructure of ferrospheres in fly ashes: SEM, EDX and ESEM analysis. J. Zhejiang Univ. Sci. A 2008, 9, 1595–1600. [CrossRef]
- Anshits, N.N.; Fedorchak, M.A.; Zhizhaev, A.M.; Sharonova, O.M.; Anshits, A.G. Composition and Structure of Block-Type Ferrospheres Isolated from Calcium-Rich Power Plant Ash. *Inorg. Mater.* 2018, 54, 187–194. [CrossRef]
- Shende, D.Z.; Wasewar, K.L.; Wadatkar, S.S. Target-Specific Applications of Fly Ash Cenosphere as Smart Material. In *Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications*; Kharissova, O.V., Martínez, L.M.T., Kharisov, B.I., Eds.; Springer International Publishing: Cham, Switzerland, 2020; pp. 1–22. [CrossRef]
- 83. Yeung, K.-W.; Tang, C.-Y.; Hu, R.; Lam, C.-H.; Law, W.-C.; Tsui, G.C.-P.; Zhao, X.; Chung, J.K.-H. Fabrication of ceramic bioscaffolds from fly ash cenosphere by susceptor-assisted microwave sintering. *J. Eur. Ceram. Soc.* **2022**, *42*, 4410–4419. [CrossRef]
- 84. Yoriya, S.; Tepsri, P. Crystal growth on cenospheres from high-calcium fly ash. Crystals 2021, 11, 919. [CrossRef]
- 85. Scaccia, S.; Vanga, G.; Gattia, D.M.; Stendardo, S. Preparation of CaO-based sorbent from coal fly ash cenospheres for calcium looping process. *J. Alloys Compd.* **2019**, *801*, 123–129. [CrossRef]
- 86. Nakonieczny, D.S.; Antonowicz, M.; Heim, T.; Swinarew, A.S.; Nuckowski, P.; Matus, K.; Lemanowicz, M. Cenospheres-Reinforced PA-12 Composite: Preparation, Physicochemical Properties, and Soaking Tests. *Polymers* **2022**, *14*, 2332. [CrossRef] [PubMed]
- Cheng, Z.; An, J.; Li, F.; Lu, Y.; Li, S. Effect of fly ash cenospheres on properties of multi-walled carbon nanotubes and polyvinyl alcohol fibers reinforced geopolymer composites. *Ceram. Int.* 2022, 48, 18956–18971. [CrossRef]
- Bijekar, S.; Padariya, H.D.; Yadav, V.K.; Gacem, A.; Hasan, M.A.; Awwad, N.S.; Yadav, K.K.; Islam, S.; Park, S.; Jeon, B.-H. The State of the Art and Emerging Trends in the Wastewater Treatment in Developing Nations. *Water* 2022, 14, 2537. [CrossRef]
- 89. Musyoka, N.M.; Petrik, L.F.; Balfour, G.; Gitari, W.M.; Hums, E. Synthesis of hydroxy sodalite from coal fly ash using waste industrial brine solution. *J. Environ. Sci. Health Part A* **2011**, *46*, 1699–1707. [CrossRef] [PubMed]
- 90. De Gennaro, B.; Aprea, P.; Liguori, B.; Galzerano, B.; Peluso, A.; Caputo, D. Zeolite-rich composite materials for environmental remediation: Arsenic removal from water. *Appl. Sci.* **2020**, *10*, 6938. [CrossRef]

- 91. Karakaya, M.Ç.; Karakaya, N.; Yavuz, F. Geology and Conditions of Formation of the Zeolite-Bearing Deposits Southeast of Ankara (Central Turkey). *Clays Clay Min.* 2015, *63*, 85–109. [CrossRef]
- Kumar Inwati, G.; Kumar, P.; Roos, W.D.; Swart, H.C. Thermally induced structural metamorphosis of ZnO:Rb nanostructures for antibacterial impacts. *Colloids Surf B Biointerfaces* 2020, 188, 110821. [CrossRef]
- Kumar, P.; Inwati, G.K.; Mathpal, M.C.; Ghosh, S.; Roos, W.D.; Swart, H.C. Defects induced enhancement of antifungal activities of Zn doped CuO nanostructures. *Appl. Surf. Sci.* 2021, 560, 150026. [CrossRef]
- 94. Inwati, G.K.; Kumar, P.; Roos, W.D.; Swart, H.C.; Singh, M. UV-irradiation effects on tuning LSPR of Cu/Ag nanoclusters in ion exchanged glass matrix and its thermodynamic behaviour. J. Alloys Compd. 2020, 823, 153820. [CrossRef]
- 95. Astuti, W.; Chafidz, A.; Wahyuni, E.T.; Prasetya, A.; Bendiyasa, I.M.; Abasaeed, A.E. Methyl violet dye removal using coal fly ash (CFA) as a dual sites adsorbent. *J. Environ. Chem. Eng.* **2019**, *7*, 103262. [CrossRef]
- 96. Balarak, D.; Zafariyan, M.; Igwegbe, C.A.; Onyechi, K.K.; Ighalo, J.O. Adsorption of Acid Blue 92 Dye from Aqueous Solutions by Single-Walled Carbon Nanotubes: Isothermal, Kinetic, and Thermodynamic Studies. *Environ. Process.* **2021**, *8*, 869–888. [CrossRef]
- 97. Balarak, D.; Raju, R.; Igwegbe, C.A.; Ighalo, J.O. Ultimate Eradication of Acid Orange 7 from Contaminated Liquid via Synthesized Mesoporous Goethite. *J. Turk. Chem. Soc. Sect. B Chem. Eng.* **2021**, *4*, 13–26.