#695 - APPLICATION OF ZEOLITE IN CONSTRUCTED WETLANDS FOR TREATMENT OF AGRICULTURAL WASTEWATER.

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Abstract:

This paper explores an innovative, multi-phase approach to enhancing agricultural wastewater treatment through constructed wetlands, targeting the reduction of pollutants. In addition to the necessity of using readily available, plentiful materials and the requirement to substitute sustainable compounds derived from renewable resources for chemicals derived from fossil fuels. To improve filtration and adsorption, all wetland beds are layered with different materials like, biochar and zeolite as an environmental friendly material and plant with various wetland plants. Over the course of the project, progressively complex treatments are introduced in different phases to maximise pollutant reduction. This paper intends to create optimised constructed wetlands for agricultural wastewater reclamation by combining natural and engineered treatment strategies, ultimately supporting sustainable green infrastructure solutions and assess the impact of Zeolite in wastewater treatment. The results will offer important insights into how artificial wetlands can improve water quality by focusing on a variety of pollutants, providing a useful, environmentally responsible method of managing wastewater in agricultural settings, the result shows using Zeolite in constructed wetlands is highly effective for reduction of heavy metals.

INTRODUCTION:

Because of its low initial cost, ease of management and operation, ecological advantages, effectiveness in removing pollutants, and wide range of applications, constructed wetlands (CWs) are frequently used in water treatment. The three steps of the CW purification process substrate filtration and adsorption, plant absorption, and microorganism breakdown were found to be separated, with substrate purification coming first. CW substrate encourages the production of microbial films, provides vital living space for microorganisms, and fosters plant growth. Adsorption, precipitation, and ion exchange are the processes that enable the

substrates' distinct physical and chemical characteristics to separate and enrich pollutants in wastewater Tota-Maharaj & Hills, 2023). Different substrates are now used in CW, Zeolite substrates for CWs have a wide range of applications and an excellent purifying effect. Zeolites come in a wide variety and are widely available. According to statistics, China alone has found over 400 zeolite deposits, with total reserves reaching 3 billion tonnes (Yang et al., 2021). There are two types of zeolite: natural and artificial. In addition to expanding the range of applications for zeolite in water treatment, using it as a CW substrate raises the material's value. Natural zeolite's purifying capabilities as a CW substrate were improved by significantly increasing its adsorption through modification. The skeleton of natural zeolite is made up of the silicate-oxygen tetrahedron and the alumina-oxygen tetrahedron. It possesses a high ion exchange capacity, a large specific surface area (SSA), and a robust adsorption capacity. One type of green adsorbent substance that is frequently utilised in water filtration is zeolite(Choi et al., 2016). It was discovered that zeolites with varying particle sizes had significantly diverse purifying effects on various sewage contaminants. Zeolite may compensate for the shortcomings of a single substrate and greatly enhance the purifying effect when combined with other materials as the CW substrate. Zeolite adapted as the CW substrate was shown to have a high heavy metal removal effectiveness (Chen et al., 2016).Its utilisation in CW substrates has excellent potential for wastewater purification at both high and low concentrations. As CW's substrate, zeolite has a long-lasting and effective purifying impact on low-polluted water. Despite the fact that considerable research has been done on zeolites as CW substrates, neither the purification process nor the prospective applications of zeolites in CW have been extensively explored. It was discovered that zeolite, the CW substrate, removed antibiotics and antibiotic resistance genes at a rate of over 85%. Total nitrogen (TN), NH_4, and organic matter were found to benefit much from zeolite as the CW substrate. In particular, the purifying impact can be greatly enhanced by the nitrogen removal substrate of CW. This research delves deeply into zeolites with the goal of improving CW purification (Wang et al., 2025). This study reviews current research findings, discloses the advantages and disadvantages of zeolite as a CW substrate in terms of mechanism, and serves as a significant reference for the configuration of compound CW substrates.

1.1. Pollutant adsorption process

Scanning electron microscopy (SEM) images show the zeolite's grain shape and visual structure. Zeolite has porous, protuberant, and rough-like shape, resulting in a high SSA. Sodium bicarbonate was discovered to disintegrate into a high amount of CO_2 and water vapour to generate voids when used as a pore-forming agent, and the pore structure was much enhanced. Zeolite removes contaminants from water primarily by filtration and adsorption (Collins et al., 2020).

1.2. Sustainable utilisation of zeolite

Zeolite has a porous, protuberant, and rough-like structure, resulting in a high SSA. When used as a pore-forming agent, sodium bicarbonate decomposes into a considerable amount

of CO2 and water vapour, leaving voids and significantly enhancing pore structure. Zeolite removes contaminants from water primarily through filtration and adsorption. Sewage flows over the zeolite substrate, which absorbs contaminants while allowing water molecules to pass through. The regeneration and modification of zeolite can increase its service life, which is crucial for its long-term development. The invention of synthetic zeolite helps to reduce the zeolite scarcity. Zeolite contributes to the realisation of renewability. Zeolite contributes to the attainment of renewability. Zeolite regeneration technology is divided into three categories: chemical regeneration, physical regeneration, and biological regeneration, with the latter being the most widely used. According to relevant study, natural zeolite as a CW substrate employs biological regeneration technology, which is both inexpensive and efficient. It has the potential to realise the long-term use of zeolite while also lowering CW operational costs(Czuma et al., 2020).

Biological regeneration technology has limitations such as a long cycle and low efficiency, so more research is needed. Modifying zeolite is an important approach for increasing the purifying impact of zeolite as a CW substrate and extending its usage life. The most typical modification processes include acid and alkali treatment, ion exchange, heat treatment, microwave therapy, and surface modification (carrier and skeleton modification). The thermal modification process includes heating the zeolite, eliminating water and organic matter, straightening the zeolite channel, increasing the SSA, and boosting its adsorption and ion exchange capacity. Acid modification entails dissolving impurities in the zeolite channel with inorganic acid, opening the hole, and increasing the zeolite's SSA(Zuo et al., 2019).

METHODOLOGY:

2.1. Vertical flow CW (VFCF) setup

Figure.1 depicts the intended CWs. A cylinder with a height of 100 cm and a diameter of 25 cm will be utilised to treat wastewater. Labrador plants were transplanted inside each CW, which functions as a vertical subsurface flow CW (VSFCW). The CW, which comprised merely a gravel substrate layer, served as a blank for assessing the performance of the biochar and zeolite substrate layer, as well as the plants. Zeolite, and gravel had diameters of around 2-3 cm. Table 1 displays their parameters.
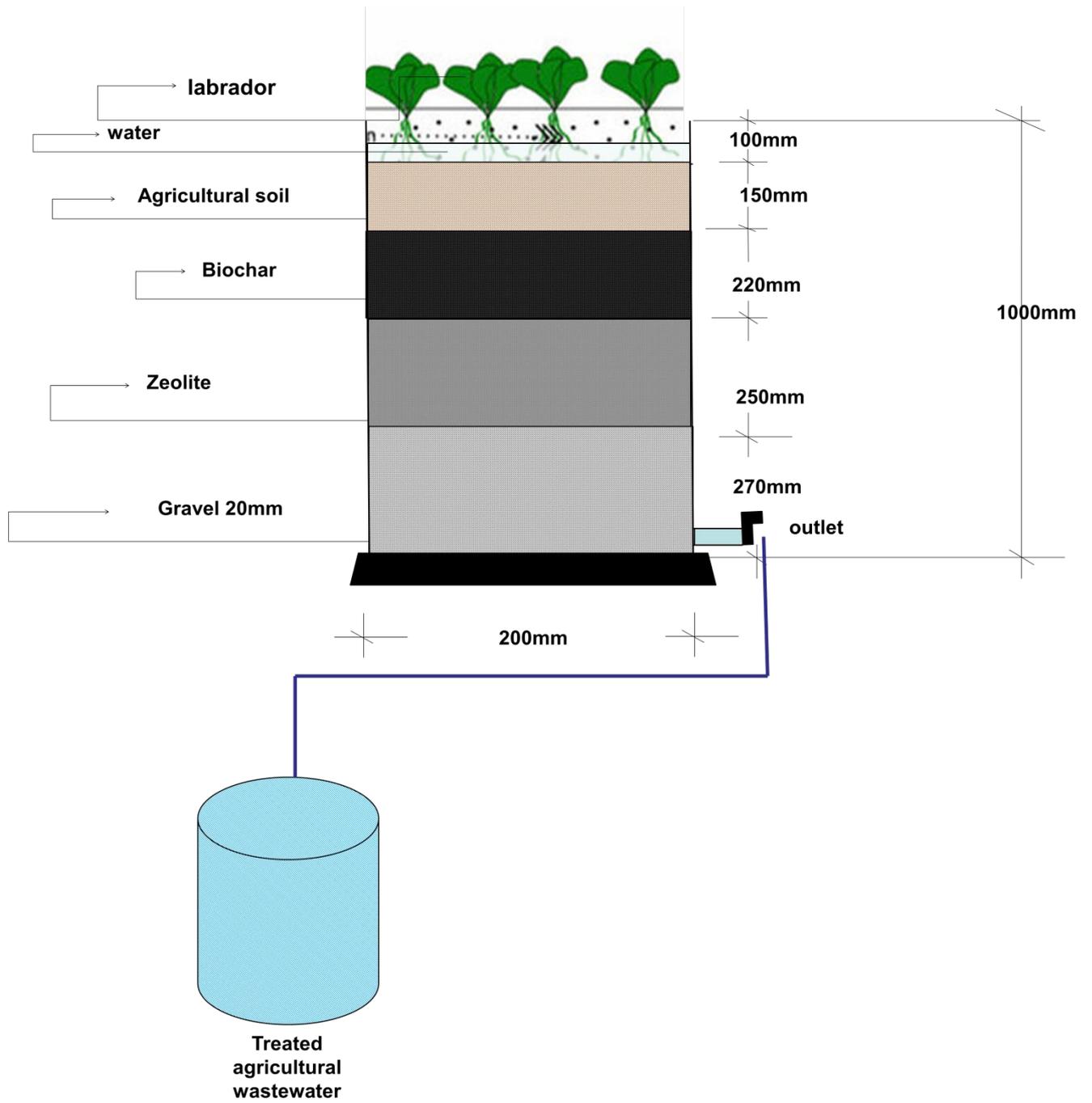
labrador

water

Agricultural soil

Biochar

Zeolite

Gravel 20mm

100mm

150mm

220mm

250mm

270mm

outlet

1000mm

200mm

Treated
agricultural
wastewater

Figure 1: the designed CWs

RIG		
Wetland plant	Labrador	
Water resource	agricultural run off	
	Bucket size	**200mm (D) x 1000mm (H)**
Layer1	Gravel 10mm – 20mm	270mm
Layer2	Zeolite	250mm
Layer3	Biochar 1-2mm	220mm
Layer4	Agricultural Soil	150mm

DISCUSSION AND EXPECTED RESULTS:

Zeolite has been extensively explored as an effective substrate in constructed wetlands (CWs) for wastewater treatment due to its high cation exchange capacity and porous nature. Research findings from multiple journal papers show that it has a significant impact on enhancing the removal efficiency of pollutants such as ammonium, total nitrogen, heavy metals, and phosphorus.

1.1. Ammonium and Nitrogen Removal:
Zeolite's ion-exchange ability efficiently removes ammonium (NH_4^+-N) from wastewater. For example, one study discovered that wetlands constructed with zeolite as a substrate had ammonium removal efficiencies ranging from 84.0% to 99.9%, as well as total nitrogen removal efficiencies ranging from 80.3% to 92.1%. Another study discovered that adding zeolite and biochar to designed wetlands improved simulated ammonium removal efficacy by 24.3% in vertical flow systems and 46.6% in horizontal flow systems when compared to unmodified systems (Table.2).

1.2. Heavy Metal Removal:
Zeolite's adsorption properties contribute to the effective removal of heavy metals from wastewater. In one study, artificial wetlands containing a zeolite-slag hybrid substrate recovered heavy metals from rural landfill leachate at a rate of almost 90%. Furthermore, batch experiments demonstrated significant zeolite loading rates of lead (91.6 mg/g), chromium (60.8 mg/g), and copper (47.4 mg/g), showing its potential for treating industrial effluents.

1.3. Phosphorus Removal:

While zeolite is not commonly associated with phosphorus removal, certain studies have investigated its potential in this area. For example, a study discovered that artificial wetlands treated with zeolite retained more phosphorus, with concentrations dropping considerably with depth in the wetland bed (He et al., 2017).

1.4. Combined Substrate Use:

Combining zeolite with other materials, like as ceramsite or biochar, can boost the treatment efficiency of artificial wetlands. A study discovered that combining zeolite and ceramsite as substrates resulted in a significantly stronger purifying influence on ammonium in sewage than using zeolite alone.

Table 2: literature review on using Zeolite in CW

Wetland Type	Substrate Configuration	Target Pollutant(s)	Removal Efficiency / Key Findings	Reference
Subsurface Flow CW	Zeolite + Slag	Heavy Metals	~90% removal for rural landfill leachate heavy metals	Zhang et al. (2017)
Vertical Flow CW	Zeolite + Biochar	Ammonium (NH_4^+-N)	24.3% ammonium removal compared to unamended	Wang et al. (2020)
Horizontal Flow CW	Zeolite	Ammonium, TN	84.0–99.9% NH_4^+-N; 80.3–92.1% TN removal	Liu et al. (2024)
Lab-scale Batch Test	Zeolite	Pb, Cr, Cu	Pb: 91.6 mg/g, Cr: 60.8 mg/g, Cu: 47.4 mg/g adsorption	Gao et al. (2020)
Subsurface CW	Zeolite + Ceramsite	Ammonium	Improved performance vs. zeolite-only systems	Yang et al. (2021)

4. CONCLUSION

The CW substrate was examined using zeolite characteristics. The key results are that zeolite has a big surface area, an excellent pore structure, and a high adsorption capacity for NH4. Zeolite, as a CW substrate, has an excellent purifying impact on NH4 in sewage. The combination substrate of zeolite and ceramsite provides a higher purifying impact on CW. The investigation on the mechanism of substrate purification of CW using zeolite as the main substrate has to be strengthened, and it is advantageous to boost the purification impact of CW and production. A modified biochar/zeolite built wetland effectively removed

contaminants from synthetic wastewater. To summarise, including zeolite into artificial wetlands improves the removal efficiency of a variety of pollutants, particularly ammonium and heavy metals. Its effectiveness can be increased even further when combined with different substrates, making it a valuable component in the design and optimisation of engineered wetland systems for wastewater treatment.

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