"Enhancing Indoor Air Quality: Utilization of Coffee-Zeolite Infused Hydrogel for Effective Reduction of CO2 & VOC's in Indoor Spaces"

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Abstract:

Coffee-Zeolite infused hydrogel provide a facile platform for developing solid adsorbent for CO_2 capturing in indoor spaces. In this present study, we synthesis a novel hydrogel for capturing CO_2 through the incorporation of a composite material composed of Cellulose, Coffee, and Zeolite infused hydrogel. The hydrogel provides a porous three-dimensional matrix for enhanced water adsorption, while coffee grounds offer natural adsorption capabilities of VOC's (Volatile Organic Compound) and zeolite acts as a selective molecular sieve and enhancing the O_2 in the indoor spaces. The impact of the Coffee-Zeolite infused hydrogel on indoor air quality was investigated by assessing its ability to adsorb other pollutants and VOCs commonly found in indoor environments. The hydrogel was further characterized by X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), Scanning electron microscopy (SEM), UV Spectroscopy and In-vitro antimicrobial testing. SEM demonstrated that the prepared hydrogel had an interconnected pores with the size range of 50nm – 80nm. The XRD showed the composite structure of hydrogel and FTIR revealed the in-corporation of coffee-zeolite and cellulose infusion. The in-vitro anti-microbial testing was carried out against E. coli, C. albicans and S. aureus it exhibits an excellent inhibition zone. The in-vitro biodegradation studies show a coffee-zeolite enrich layer on the surface of soaked hydrogel in different pH. Thus, our preliminary studies conclude that the coffee-zeolite infused hydrogel could be an ideal hydrogel for better CO_2 & VOC's capturing adsorbent. However, further research studies are needed to confirm the use of synthesized hydrogel adsorbent for indoor CO_2 & VOC's.

Keywords: Indoor Air Quality, CO2 Capturing, Coffee-Zeolite Infusion, Hydrogel

Introduction:

Since the Industrial Revolution, air pollution has become a crucial threat to human health and the environment. The air pollution transfer from outdoors affects indoor air quality severely causing high risks of health issues to mankind during long-term exposure to the toxic gases. Considering that people typically spend more than 90% of their lives in indoor spaces with low air exchange rates, the adoption of effective control measures has become a critical issue [Pourjavadi et al. 2004]. Nonetheless, concerns about poor indoor air quality have increased, and the growing recognition of the problem provides an opportunity for the advancement of indoor air purifying technologies [Wang et al. 2016]. Carbon dioxide emissions are a major environmental concern and capturing the CO2 is critical for reducing greenhouse gas emissions and for natural gas processing. This can be achieved through physical or chemical approaches and the captured CO2 can then be stored, for example, in underground geological structures. This technology is known as carbon capture and storage (CCS) [Zhu et al. 2000]. According to a WHO report, NOx and VOCs, including benzene, polycyclic aromatic hydrocarbons (especially benzo[a]pyrene), trichloroethylene, tetrachloroethylene, and formaldehyde, have a myriad of indoor sources, and their concentrations often exceed ranges that raise health concerns [Zhu et al 2000]. Among the proposed alternatives, solid adsorbents are receiving substantial attention due to their ability to rapidly and reversibly capture CO2 while minimizing corrosion issues [Wang et al. 2013]. Hydrogels can be one way to achieve this since they consist of a polymeric network that absorbs and holds a significant amount of liquid within its cross-linked structure. Hydrogels offer synthetic and structural flexibility so the shape, size, stiffness, morphology, and chemical structure can be varied. [Wang et al. 2013, Cao et al. 2021]. At the same time, hydrogels are readily accessible, affordable, and non-toxic. In order to remove particulate pollutants [Chamas et al. 2020], traditional air filters typically use four main physical filtration mechanisms: sieving, interception [Sinclair et al. 1976], impact, and diffusion [Ahmed et al. 2015]. These mechanisms are based on based on petroleum synthetic polymers, such as polyethylene and polypropylene [Geyer et al. 2017]. Inevitably, these polymer-based filters are difficult to degrade after use and can easily cause secondary pollution to the environment [Li et al. 2016]. Hydrogels can be one way to achieve this since they consist of a polymeric network that absorbs and holds a significant amount of liquid within its cross-linked structure [Zhang et al. 2019]. Currently, most of the membranes are fabricated from fossil-based polymers, including polyethylene (PE), polypropylene (PP), polysulphone (PSf), poly(vinylidene fluoride) (PVDF), polyimide (PI), and poly(benzimidazole) (PBI), among others. The previous study has indicated that about 12% of all polymers get incinerated after use (hence releasing CO2), and 80% end up in landfills, which eventually find their way into the ocean [Mamaghani et al. 2017]. Although membranes prepared from these polymers exhibit excellent performance, these fossil-based polymers do not biodegrade and can break apart into microplastics. Certainly, these microplastics are adversely impacting the environment and other species although their potential hazardous effects to humans are yet unknown [Morganti et al. 2020]. However, it is only soluble in a handful of solvents, limiting its fabrication into membranes at an industrial scale [Li et al. 2014]. The escalating levels of carbon dioxide (CO2) in indoor environments pose a critical risk factor to human health and well-being. As the global population continues to urbanize and spend a significant portion of time indoors, understanding and addressing the impact of elevated CO2 concentrations becomes paramount. Indoor air quality (IAQ) is intricately linked to occupant health, productivity, and overall comfort, making it imperative to explore innovative strategies for CO2 reduction within enclosed spaces. This paper explores the novel application of a composite material composed of hydrogel blended with coffee and zeolite as a promising solution to address the escalating risk of indoor CO2 exposure. The integration of these materials leverages their unique properties to enhance CO2 absorption and contributes to a comprehensive approach to indoor air quality improvement. Through systematic investigation and experimentation, this study seeks to elucidate the efficacy of this composite material in achieving sustained reductions in indoor CO2 levels, providing valuable insights for advancing the field of indoor environmental quality management.

2. Materials & Methods

2.1. **Materials**

Sodium Alginate, Cellulose Microcrystalline, and Zeolite were purchased from Sigma-Aldrich Inc. The solvents Glycerol and Glutaraldehyde were purchased. Pure-grained coffee seeds were purchased. Deionized water was prepared by laboratory pure water systems. All materials and solvents were used without further purification.

2.2. **Preparation of Hydrogel Base**

In this experiment, 100 mL of distilled water was heated at the range of 70 to 80 C and the 1.5 g of sodium alginate was added little by little to it. The as-prepared solution is also stirred at the range of 600-800 rpm using a magnetic stirrer until the sodium alginate is dissolved completely. 1.5 g of cellulose is added to the as-prepared mixture and stirred at 600 rpm for 15-20 minutes. 10mL of the solvents, glycerol, and glutaraldehyde were added to the solution and stirred for 30 mins. Then, 3 g of coffee and zeolite were added to the as-prepared mixture which are used as adsorption and molecular sieve respectively, and stirred at 600-800 rpm for 30 mins and 45 mins respectively. The illustration of the preparation of the primary solution is shown in the fig.1

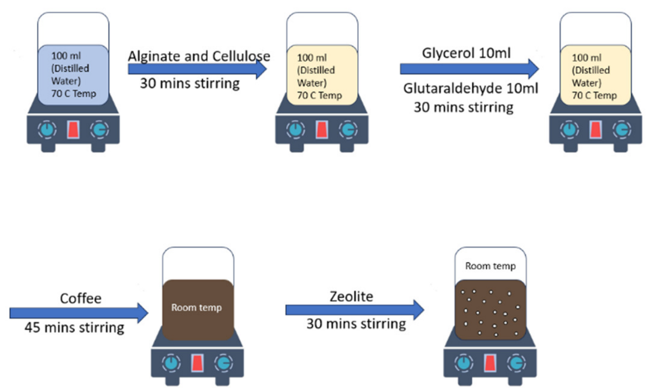

Fig 1: shows a preparation of hydrogel base

2.3. **Synthesising of Hydrogels**

5g of Calcium Chloride was added to the 100 mL of distilled water which is used as a cross linker. After the $CaCl_2$ was dissolved completely, the primary solution was added to the cross-linker drop-by-drop using a dropper as shown in fig.2. The spherical hydrogel balls were formed inside the cross-linker solution and left undisturbed for 30 min at room temperature. After that, the hydrogel balls were washed and rinsed with distilled water twice for the eradication of impurities on the surface.

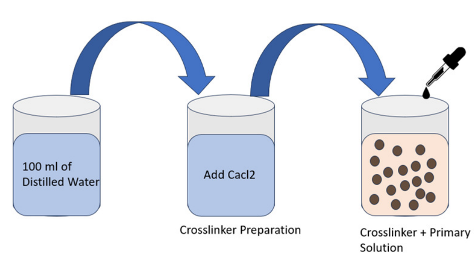

Fig 2: shows a preparation of hydrogel base with crosslinker

2.4. Characterization of Hydrogel Beads: XRD (X-ray diffraction analysis) is a technique that gives a detailed output and information about the crystallographic structure, chemical composition and physical properties of a material thus facilitate in the characterization and study of the substance. UV Characterization generally refers to the analysis and assessment of materials or substances using ultraviolet (UV) radiation in which the absorbance of the material is studied as a function of wavelength.

Scanning Electron Microscope (SEM) provides a high-resolution magnified image of the test sample that can be used to evaluate the gaps, surface structure, flaws, contaminations etc. The incident beam of electron moves across the sample surface and interacts with the sample and the image of the sample is built. FTIR (Fourier Transform Infrared Spectrometer) is a process to identify the unknown composition of the states of matter. It is to evaluate the material's molecular structure and composition, the various wavelengths (Infra-red-light energy) that are absorbed by the sample is measured

2.5. In-vitro Biodegradation tests are essential for assessing the chemical stability of molecules, facilitating the development of stable formulations with suitable storage condition. In our study, the dried and the wet hydrogels were subjected to degradation analysis. The samples were carefully observed and the weight ratios were measured.

2.6. In-vitro Anti-microbial activity antimicrobial activity pertains to the active agents that inhibit bacterial growth, impede the formation of microbial colonies, and sometimes eliminate microorganisms. The assessment of antimicrobial properties was conducted using the agar well diffusion method. Evaluating the antibacterial efficacy of plant extracts commonly involves employing this method. The procedure involves inoculating the agar plate surface by evenly spreading a microbial inoculum across the agar, similar to the disk-diffusion method. Subsequently, aseptically, a hole with a diameter of 6 to 8 mm is created using a sterile tip, and a volume (20–100 µL) of the antimicrobial agent or extract solution at the required concentration is placed into the well. The agar plates are then incubated under appropriate conditions for the test microorganism. The antimicrobial component diffuses through the agar medium, hindering the growth of the bacterial strain.

3. Results and Discussions:

Recent developments in nanomaterials and nanotechnology have provided novel possibilities for eliminating small particulates and gaseous contaminants from the atmosphere and decreasing their impact on human health. In recent years, the scientific community has witnessed a growing interest in developing materials and technologies aimed at reducing indoor CO2 concentrations. The global effort to combat climate change, the imperative to reduce carbon dioxide (CO2) emissions has become paramount. As a primary greenhouse gas contributing to global warming, CO2 emissions resulting from human activities such as industrial processes and fossil fuel combustion have reached unprecedented levels.

3.1. Hydrogel Preparation:

Hydrogels can indeed be utilized for carbon dioxide (CO2) capture due to their high surface area, porous structure, and ability to absorb and retain large amounts of water and other substances. Numerous techniques have been developed to fabricate highly interconnected porous hydrogel beads for CO2 capturing with the help of biomaterials such as cellulose, sodium alginate, coffee and zeolite, and so on with different combinations. As shown in table 1, five samples (alpha, beta, gamma, delta, epsilon) with different ratios of sodium alginate, cellulose, coffee-zeolite were prepared to standardize the hydrogel beads synthesis using titration method.

Each ratio of hydrogel beads preparation was performed five times.

S. No	Sample	Alginate	Cellulose	Coffee & Zeolite ratio	Result
1.	Alpha	2g	5g	1:2	Soft balls and weak
2.	Beta	3g	1.5g	1:1	Weak and fragile
3.	Gamma	3g	3g	1:1	Consistent and good hydrogels balls
4.	Delta	3g	2g	2:1	Not evenly dispersed
5.	Epsilon	3g	1.5g	2:1	Hard and inconsistent

Table 1 Shows the standardized ratio of hydrogel beads

Among the samples used to prepare the hydrogel beads sample gamma exhibited a perfect hydrogel structure than the other combination. Hence gamma sample ratio was considered combination for the preparation of hydrogel beads with perfect hydrogel structure for CO2 capturing application. Therefore, gamma sample was subjected to further characterization studies. The hydrogel beads with a diameter of 50-80nm were obtained by titration method. The homogenous mixture was obtained using this method for hydrogel beads. The standardized ratio of hydrogel beads preparation is given in table 1.

3.2. Morphological Characterization:

SEM image of hydrogel beads showed a mixed homogeneous structure at different magnification in fig 3. The SEM images 1 showed that 60% of the hydrogel beads was porous (2 & 3) shows a homogenous structure of the hydrogel beads. Franciele L et al., suggest that the amine modification of cellulose samples led to a separation of fiber bundles, especially sample CL-D-400.

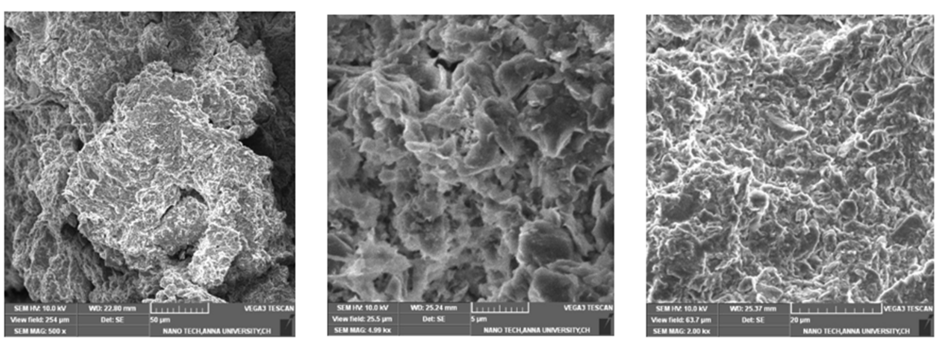

Fig 3 Shows SEM image of hydrogel beads

This may contribute to the increase of contact surface area and, consecutively, to CO2 sorption. The composite particle size was less than 150nm which were evenly distributed with the inter-connected structure. Mariana et al., suggested that the irregular pores are found on the coffee grounds adsorbents that have not yet been activated and the cavity on the pores was still loose and rough as shown in fig 3(1). The pores indicated a widening in the diameter as the structure developed into rough porous networks in the form of a honeycomb. According to Mariana et al., the sorbent that has undergone chemical and physical activation exhibits regular pore size distribution and porosity with an average pore size of 1.592µm.

3.3. Functional Characterization:

FTIR spectral analysis of hydrogel beads was represented in fig 4 cellulose exhibits the characteristic peak bands of carboxyl group (O-H stretching). The peaks at 1395-1440cm-1 are assigned to vibration of carboxyl group. The stretching vibration peak of hydroxyl group at 2947cm-1. Dayang Fazirah Binyi Abg Ahmad suggested that the broad peak at 3335 cm−1 was caused by the hydroxyl group in polysaccharides stretching vibration, which included both intramolecular and intermolecular hydrogen bonds vibration in cellulose. Daniela. M. Rodrigues et al., 2019; suggested that the infrared spectra of cellulose in all sample showed a broad band located at 3330 - 3340 cm-1, attributed to the stretching of The OH groups, a band near 2920 cm-1 associated with C-H stretching, a band at 1160 cm-1 corresponding to C-O-C asymmetrical bridge stretching, and broad bands about 1050 cm-1 and 890 cm-1 related to the cellulose structure's C-H and C-O stretching vibrations (Johar et al., 2012; Rosa et al., 2012). The main structure of sodium alginate is composed of 2 monomeric unit and in FTIR analysis of sodium alginate peaks around 884cm-1and water contains the elastic bands and the peaks falls on 3200cm-1 to 3500cm-1. The characteristic vibration C=O stretching shows the presences of aldehydes at 1720cm-1 to 1740cm-1.

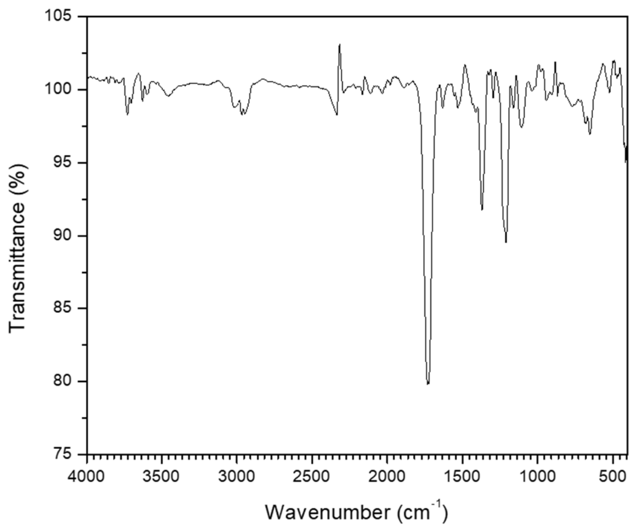

Fig 4 shows a FTIR spectra of hydrogel beads

OH, group show that hydroxyl group present at 1330cm-1 to 1420cm-1. Because of the compound's macromolecular structure, which has several intermolecular connections, the bands are typically immense. A wide variety of frequencies are exhibited by the O-H stretching vibrations at 1330cm-1 to 1420cm-1, suggesting the existence of both attached O-H bands and free hydroxyl groups in Zeolite. The absorption peaks at 1200cm-1 and 650cm-1 were assigned to the C=C stretching and C-N stretching that is linked to caffeine.

Wavelength (cm^{-1})	Chemical Bond	Functional Group
$3700cm^{-1} – 3500cm^{-1}$	O-H Stretching	Alcohol
$3000cm^{-1}$	C-H Stretching	Alkene (Intermolecular bonded)
1700 cm^{-1}	C=O stretching	Conjugated Aldehyde
1350 cm^{-1}	O-H Bending	Phenol
1200 cm^{-1}	C-N Stretching	Amine
1150 cm^{-1}	C-O Stretching	Aliphatic Ether
650 cm^{-1}	C=C Bending	Alkene

Table 2 shows a chemical bonds of hydrogel beads

3.4. Crystallographic Analysis:

The XRD analysis of the hydrogel beads showed the crystalline structure. The XRD of coffee-zeolite infused hydrogel beads revealed the typical XRD pattern of crystalline cellulose structure with different peaks at 2θ° values are showed in table 3.

No.	2-theta(deg)	d(ang.)	Height(cps)	FWHM(deg)	Int. I(cps deg)	Int. W(deg)	Asym. factor
1	36.719(4)	2.4456(2)	14545(311)	0.160(3)	2948(22)	0.203(6)	0.81(7)
2	42.943(6)	2.1044(3)	4408(171)	0.187(5)	1122(11)	0.255(12)	0.88(11)
3	63.305(5)	1.46789(10)	2862(138)	0.148(5)	558(10)	0.195(13)	1.04(15)
4	67.63(6)	1.3841(10)	53(19)	0.3(3)	36(7)	0.7(4)	1.0(18)
5	76.430(4)	1.24519(5)	5613(193)	0.170(4)	1261(14)	0.225(10)	0.97(10)

Table 3 shows a XRD 2θ° values of hydrogel beads

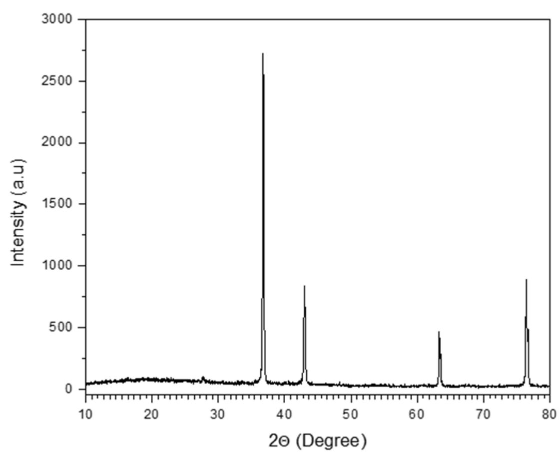

Fig 5 shows a crystallographic studies of the hydrogel beads

The degree of crystalline structure is increased along with the original cellulose content in the hydrogel beads. The crystalline size is measure from the XRD data was lower than 50nm in the hydrogel sample. Johar et al., suggest that the samples exhibit typical cellulose peaks around 2θ = 16°, 22.6° and 35°'

3.5. UV- Spectroscopy analysis:

The absorbent peaks showed up around λmax = 200-240nm for the entire concentration of coffee-zeolite infused hydrogel beads in the excitation of the surface plasmon vibration; demonstrating the development of the hydrogel beads in this UV analysis.

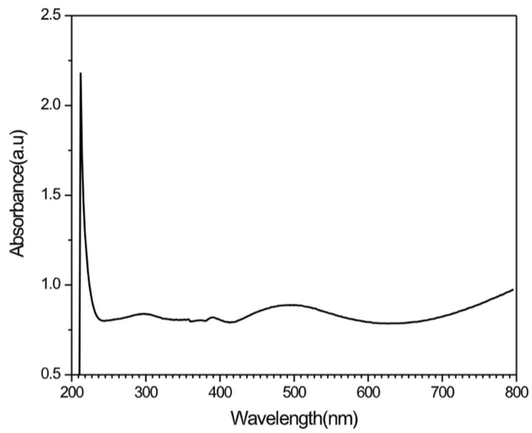

Fig 6 shows a UV spectrum of hydrogel beads

Shifting of surface plasmon groups at around 200-240nm showed in fig 6 relies upon the certain elements of coffee-zeolite. The peak position and peak shapes of the hydrogel beads shown in SEM image and the porous nature of the beads it roughly to predict the size and shapes of the hydrogel beads around 50-80nm. If the LHE (Light Harvesting Efficiency) increases, the absorbance intensity of the hydrogel beads was expanded. This can be interpreted that the function groups of the synthesized hydrogel to promote the capturing of CO_2 & VOC's in the indoor spaces.

3.6. In-vitro Biodegradation analysis:

Hydrogel bead is made up of biomaterials are utilized for capturing CO_2 & VOC's. Therefore, the biomaterials should be reabsorbed with an appropriate rate of degradation depends upon the adsorption of the CO_2 & VOC's in the indoor spaces. Ludovica et al., suggested that the choice of a bio-degradable biomaterials is great importance with regards to the capturing of CO_2 & VOC's and must be accurately done by bulky materials.

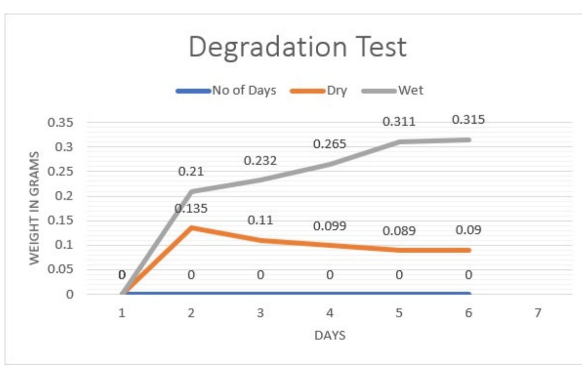

Fig 7 shows the degradation of the hydrogel beads.

Degradability of the hydrogel beads is the important characteristics for capturing CO2 & VOC's because it is crucial for the adsorption, integrity and longevity on the indoor spaces. Fig 7 shows the swelling and shrinking ratio of the coffee-zeolite infused hydrogel beads in dry and wet environment at different time period. The dry sample had a high weight drop precent during 48hrs (ranging from 15% to 18%) compared to the wet sample treated with saline solutions. The present study showed that the degradation of the hydrogel beads is external stimuli dependent. The graph shows the degradation percent of the hydrogel beads for both wet and dry samples. After 24hrs the hydrogel beads absorbed more water from the initial weight followed by gradual increased the weight up to 72hrs under the experimental conditions. Reduction in the weight of the hydrogel beads significantly increased the degradation rate throughout the experimental period. However, the degradation rate of the hydrogel beads was slowed down in the next 4 days. We observed the weight loss during the experimental period of dry hydrogel samples.

3.7. In-vitro Anti-microbial analysis:

The antibacterial activity of plants or microbial extracts is frequently assessed using the Agar well diffusion method. The process for inoculating the agar plate surface is similar to that of the disk-diffusion approach in that it requires covering the entire surface with a volume (500ul) of the microbial inoculum. Then, a hole with a diameter of 6 to 8 mm is punched aseptically with a sterile 1000ul tip, and 100 µL of the antimicrobial agent or extract solution at desired concentration is introduced into the well. Then, agar plates are incubated at 37°C / 30°C under suitable conditions depending upon the test microorganism.

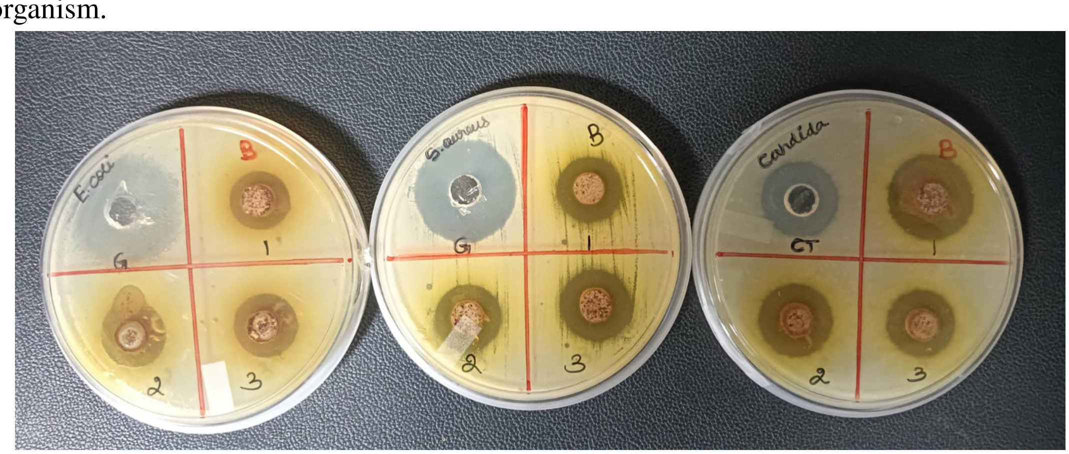

Fig 8 shows the anti-microbial analysis of the hydrogel beads.

Table 4 Zone of Inhibition sizes (in mm) average for triplicate samples determined by Agar diffusion method.

S.no	SAMPLE (100 ul)	Zone of Inhibition for Microorganism (in mm)		
		E. COLI	***S. AUREUS***	***CANDIDA***
1.	SAMPLE A	18mm	20mm	21mm
2.	GENTAMYCIN	30 mm	28mm	-

The antimicrobial agent diffuses in the agar medium and zone of inhibition checked after incubation period. Here gentamycin is used as a control for bacterial culture and clotrimazole is used as antibiotic control for Yeast culture. Two bacterial strains (*E. coli, S. aureus*- Gentamycin used as control antibiotics) and one yeast strain *candida albicans* (clotrimazole used as control antibiotics*)* were used for the study. Three wells (triplicates) for each sample in each plate (100 ul of the sample was loaded onto each well). The inhibition zone shown in the table 1.4 for all the samples.

4. Conclusion:

The findings suggest that the hydrogel infused with coffee and zeolite exhibits promising potential for adsorbing CO2 in indoor environments. Further exploration through CO2 adsorption tests could elucidate the material's capacity and specific characteristics. Given its cost-effectiveness and straightforward preparation process, this material is conducive to large-scale production. Implementing this hydrogel could notably contribute to reducing CO2 levels indoors, potentially revolutionizing indoor air quality and respiratory health.

Conflict of Interests

The authors declare that there is no conflict of interests to publish this research article in your esteemed journal.

Ethical Approval & Consent to Participate

“Not Applicable”

Funding

"Not Applicable"

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