ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2455

Production of Porous Biochar from Cowdung and its Application

Prachi Singh[1]; Rahul Kumar[1]; Avinesh Singh[1]; Md Sameer[1]; Manish S. Khodwe[2]
Department of Chemical Engineering, Chandigarh University, Punjab- 140413, India

Abstract:- Porous activated carbon (PAC) powder is prepared from solid bio-waste - cow dung samples (CD). UV- Spectroscopy confirms the absorption rate of activated porous biochar at different concentration solutions(in ppm).The activation process is carried out by phosphoric acid and sodium hydroxide treatment followed by calcination at different temperature condition. XRD pattern confirms the amorphous phase formation with graphitic nature for different precursor utilization. SEM analysis shows the uniform and hierarchical porous network formation and aggregated particle with tiny. X-ray analysis confirms the formation of graphitic carbon and porous morphology for sample activated at increased calcination temperature. The elemental composition of as prepared carbon samples is determined by SEM and confirms the formation major carbon content existence. The obtained product is observed for the dye removal process wherein the specific amount of PAC is added to the Methylene Blue(MB) dye solutions and the absorption rate is observed through uv-spectroscopy.

***Keywords*:-** *Pyrolysis, Biochar, Porous Activated Carbon Powder, Methylene Blue, Solid Waste Management, SEM Analysis, XRD, UV-Spectroscopy*.

I. INTRODUCTION

Finding sustainable and affordable wastewater treatment options has become more important as environmental concerns over the disposal of wastewater from different businesses grow. The use of biochar, a carbon-rich substance made from biomass, has drawn the most attention among these alternatives because of its potential for use in water remediation applications. Biochar is a great option for adsorption-based water treatment procedures because of its porous structure, large surface area, and varied chemical makeup. Biochar has historically been made from feedstocks such wood chips, leftover agricultural waste, and biological waste products. In order to improve the sustainability and economic viability of biochar inghsynthesis, recent research has instead concentrated on investigating substitute feedstocks. Cow dung, a common agricultural waste product with a high organic carbon content, is a good candidate for the synthesis of biochar. Pyrolysis of biomass occurs under regulated temperature and oxygen availability conditions to produce biochar. Volatile substances are pushed out during pyrolysis, leaving behind a porous residue rich incarbon. Biochar undergoes a post-treatment process called activation, which increases its surface area and porosity and improves its suitability for adsorption uses. Because activated biochar has a greater affinity for both organic and inorganic pollutants found in wastewater, it provides an effective way to purify water. Our goal in this project is to find out how to make activated porous biochar from cow dung and assess how well it works to remove colors from wastewater. Dyes are widely utilized in many industries, including the production of paper, leather, and textiles, and their release into water bodies presents serious threats to the environment and public health. Because of their complicated chemical structures and resistance to breakdown, dyes are generally difficult to remove from wastewater using conventional treatment procedures. Because activated porous biochar has a high adsorption capacity and selectivity towards organic compounds, it presents a feasible alternative for dye removal. Through the utilization of cow dung as a feedstock for biochar manufacturing, this study aims to create an environmentally sustainable wastewater treatment method. Advanced analytical methods including X-ray diffraction (XRD), UV- Spectrometer and scanning electron microscopy (SEM) will be used to characterize the produced biochar and determine its physical and chemical properties. Additionally, batch adsorption tests will be conducted to evaluate the activated porous biochar's efficacy in removing dye. In order to maximize the treatment conditions, the effects of different parameters on the adsorption process including temperature, pH, contact time, and initial dye concentration will be examined. To comprehend the kinetics and mechanism of dye adsorption onto the surface characteristics of biochar, the obtained findings will be studied. In addition to producing a range of goods including meat and milk, the livestock industry also produced a lot of manure and excrement, which, if not properly handled, may have a negative impact on the quality of the environment. The presence of cellulose- derived organics, nutrients (like nitrogen and phosphorus), and other constituents (like pathogens and heavy metals) in livestock manure is responsible for several major forms of environmental pollution related to waste management, including surface water eutrophication, pathogen and nitrate leaching, excess nutrients and heavy metal buildup in the soil, and the release of odorants (like ammonia and hydrogen sulfide) and greenhouse gas emissions (like methane and carbon dioxide). By using different approaches for the removal of

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2455

such pollutants, multiple scientists have conducted diverse investigations with the goal of reducing the pollution load on the hydrosphere. These methods can be broadly classified into three categories: biological methods, like the activated sludge process, which uses enzymes or microorganisms; physical methods, like adsorption, membrane filtration, and coagulation/flocculation; and chemical methods, like ozonation, By using different approaches for the removal of such pollutants, multiple scientists have conducted diverse investigations with the goal of reducing the pollution load on the hydrosphere. These methods can be broadly classified into three categories: biological methods, like the activated sludge process, which uses enzymes or microorganisms; physical methods, like adsorption, membrane filtration. A side from the copious amounts of easily accessible cow excrement In the last ten years, numerous research have been conducted using cow dung as an adsorbent to be used for the reduction of contaminants. our guided our decision to use cow dung as an adsorbent in our investigation. The removal of heavy metals from aqueous solutions using cow dung as an adsorbent was examined by Ojedokun and Bello [55]. The innovative aspect of this work is its review of previous research on the sequestration of various contaminants from aqueous environments using adsorbents derived from cow dung. The manufacture of cow dung-based adsorbents and their adsorption performance are covered in the study. Reviews of thermodynamic, kinetic, and isothermal investigations, mechanism, regeneration, and competitive adsorption were also conducted. investigate. Cow dung has been used as an adsorbent to remove heavy metals from aqueous solutions; Ojedokun and Bello [55] examined this use. Cow dung- based adsorbents have been investigated for the removal of several types of contaminants from aqueous environments due to their availability across multiple continents. For convenience and clarity, the information in the following subsections is organized according to the major categories of adsorbents: unmodified cow dung (UCD), cow dung activated carbon (CDAC), and cow dung biochar (CDC). A substance high in carbon produced by biomass photolysis is called biochar. Pyrolysis, a carbonization process used to produce biochar, results in a simultaneous drop in the amounts of oxygen and hydrogen and an increase in carbon content as temperature rises. Active carbon can be prepared using the biochar. Although both activated carbon and biochar are carbon-rich materials, their characteristics differ. Typically, biochar is not entirely carbonized as pyrolysis, the process used to produce it, frequently occurs at low temperatures (<500◦C). Comparing activated carbon to biochar that merely undergoes the carbonization process, however, reveals that the surface areas and internal pore architectures of activated carbon are significantly improved and enhanced following physical and chemical activation. Therefore, biochar could serve as a raw material for the production of activated carbon. Many studies employed biochar as a raw material.

II. MATERIALS AND METHODS

Cow Dung was chosen as our raw material for this research project which was received from cow farm in Zirakpur, Punjab. It is the excrement produced by cattle, primarily consisting of undigested plant material along with some minerals and water. It's a readily available agricultural waste product that can be collected from livestock farms or rural areas.

- The choice for the selection of this as raw material is because :
- Renewable resource
- Abundance
- Biochar produced is versatile and can be used for various applications such as soil remediation, electrode fabrication, Waste management
- Environmental friendly

➢ *Laboratory Equipment and Chemicals*

Various glasswares and equipment were used for different functions while performing the project as mentioned :-

- Pestle &Mortar: for grinding the raw material into fine pieces.
- Measuring balance: to measure the amount of different sample of CD.
- Crucibles: to collect and store the material.
- Volumetric Flask: for preparation of stock solution (500 ml);for preparation of different concentrated solution of different ppm(50 ml).
- UV- spectrophotometer: for observing absorption rate of different ppm solution for standard analysis.
- Muffle furnace: for conducting pyrolysis.
- Oven: to remove moisture(drying).
- Funnel: to carry out filtration.
- Filter paper: for continuous washing of activated biochar.
- Beakers: used for holding liquids.
- Magnetic Stirrer: for properly mixing of activating agent with biochar.
- Spatula: for levelling powders.
- pH strips: for identifying pH of solution while neutralising the activating agent during washing.
- Chemicals (Sodium hydroxide and phosphoric acid): activation agent

➢ *Preparation of Carbonized Sample (Biochar)*

Initially the cow dung was derived from the farm in pretty raw form which were supposed to crushed into finer particle for further process. The raw material was crushed using Pestle and mortar in five different samples of about 7.2 gm measured using measuring balance and placed in a crucible. This crushed material was further taken for carbonization where the sample was placed in the muffle furnace using a crucible which is made up of high heat resistive substance. The temperature of the muffle furnace was kept around 350- 400degree Celsius and it was ensured that the oxygen supply to the furnace is nullified using a jacket made

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2455

up of iron the material of the furnace and a cotton covering over it. This avoidance of oxygen will stop the ash formation of our sample.

- *Activation of Carbonized Sample (Biochar)*

The carbonized sample was then activated with two different methods to analyse the better adsorption capacity. The distinguished sample were prepared using as AC-01 and AC- 02.AC-01 was prepared using NaOH as an activating agent at an imperial impregnation ratio of 1:1. Initially NaOH solution was prepared by dissolving 5gm of NaOH in 20-25ml of solvent(distilled water). Later the NaOH solution was mixed to 5gm of biochar. Simultaneously agitation was achieved using a magnetic stirrer in order to get the uniform composition of NaOH- carbonized slurry. Then this slurry was transferred in the crucible (which is made up of high heat resistive substance) and firstly dried in an oven at about 110 degree Celsius for 1 hour to remove excess moisture and then kept in the muffle furnace under the ambient temperature of 250 degree Celsius for the time period of 30 minutes. The activated carbon AC- 01 so produced had basic Ph level which was then neutralized by acid wash(distilled water). This process was reluctant in nature since a lot of distilled water was consumed in neutralizing the activated carbon sample AC- 01. AC-02 was activated with H3PO4(phosphoric acid). The H3PO4 solution of 5ml was mixed in the biochar of 5gm. Simultaneously agitation was achieved using a magnetic stirrer in order to get uniform composition of KOH- carbonized slurry. Then this slurry was transferred in the crucible (which is made up of high heat resistive substance) and firstly dried in an oven at about 100 degree celsius for 1 hour to remove excess moisture and then kept in the muffle furnance under the ambient temperature of 250 degree Celsius for the time period of 30 minutes. The activated carbon AC-02 so produced had a basic Ph level which was then neutralized by acid wash(distilled water). This process was reluctant in nature since a lot of distilled water was consumed in neutralizing the activated carbon sample AC- 02.

- *Standard Analysis:*

For obtaining the standard curve for the biochar of which a stock solution of 1000ppm is prepared by dissolving 0.5 gm in 500ml of distilled water. The solution is prepared of different concentrations such as 2ppm(by dissolving 2 ml of 1000 ppm solution in 48ml of distilled water),4ppm(by dissolving 4ml of 1000 ppm solution in 46ml of distilled water),6ppm (by dissolving 6ml in 44ml of distilled water) and 8ppm (by dissolving 8ml of 1000 ppm solution in 42ml of distilled water)and10ppm each solution is heated at about 70 degree Celsius temperature by continuous stirring and the analysis of these different concentrated solution is done through UV-spectroscopy. suitable paper for publishing after a thorough analysis of submitted paper. Selected paper get published (online and printed) in their periodicals and get indexed by number of sources.

III. RESULTS AND SEM ANALYSIS

SEM images are very useful to obtain accurate details about pore structure of carbonized sample and activated carbon and the comparison between carbonized sample and activated carbon. The surface morphology of carbonized sample, activated sample, and activated sample without slow pyrolysis have been shown using the SEM analyzer. The SEM images revealed noteworthy changes in the surface morphology of carbonized was seen after activation in both cases. The surface of activated carbon shows an irregular structure, which is loaded with crystalline salt on inorganic matter such assulfur, nitrogen, and oxygen. However, it is evident from the Figurethat carbonization at 450 °C causes the elimination of volatile matter from the sample resulting in a rough and partially porous surface of the carbonized sample. Subsequently, a highly porous surface is observed on the activated carbon in the presence of NaOH and H3PO4 after carbonization at 450°C produced as shown in figure1(a,b)

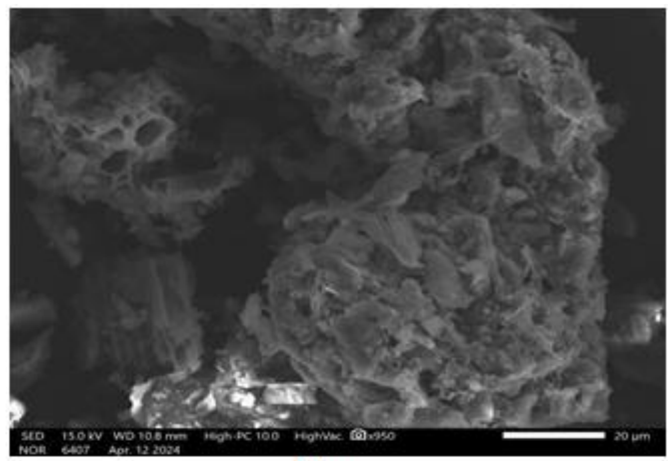

Fig:a

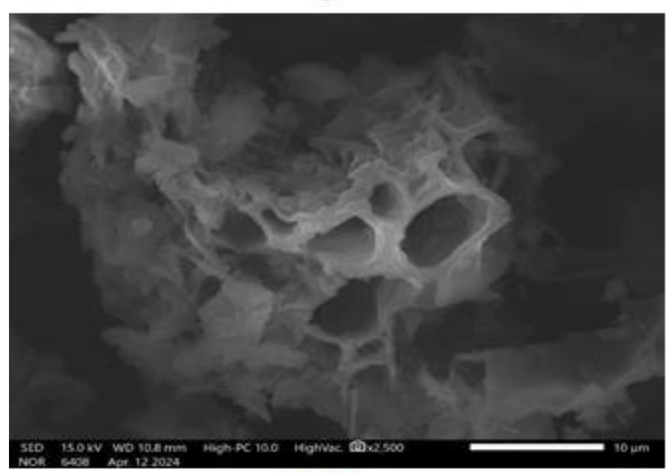

Fig:b

Fig 1 SEM Characterization for NaOH (a, b)

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2455

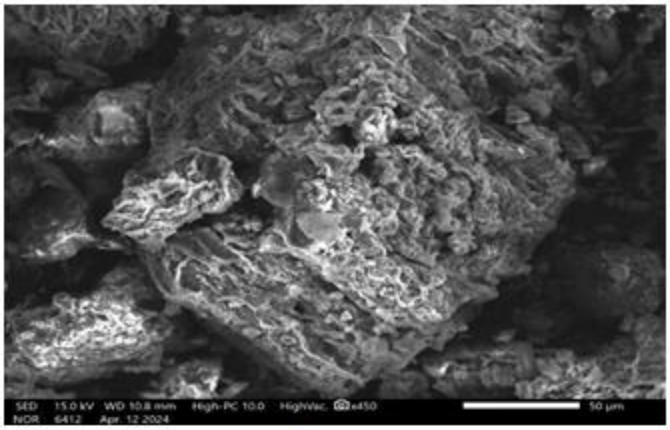

Fig: a

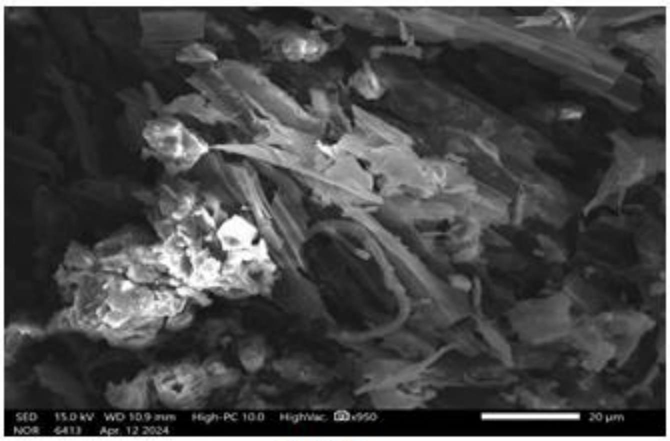

Fig: b

Fig 2 SEM Characterization for H3PO4 (a, b)

➢ *XRD Analysis*

X-ray diffraction (XRD) is a technique used to analyze the crystal structure of materials by bombarding them with X-rays and observing the resulting diffraction pattern. The XRD results are typically presented as a plot known as a theta (θ) chart, which displays the intensity of diffracted X-rays as a function of the diffraction angle (θ). Peaks in the theta chart represent specific crystallographic planes within the material. Each peak corresponds to a characteristic angle (θ) at which X-rays are diffracted by the crystal lattice of the material. The positions of these peaks (expressed in degrees) provide information about the spacing between adjacent crystal planes within the material.

Table 1: Peak List (NaOH) XRD

Index	Angle	d Value	Net Intensity	Gross Intensity	Rel. Intensity	FWHM	h,k,l
5	36.742 °	2.44408 Å	20.9	50.4	9.6%	0.202	n.a.
1	21.082 °	4.21078 Å	27.9	64.9	12.9%	0.210	n.a.
4	29.626 °	3.01297 Å	40.4	77.1	18.6%	0.347	n.a.
3	26.946 °	3.30624 Å	62.5	107	28.8%	0.232	n.a.
2	26.679 °	3.33870 Å	217	262	100.0%	0.197	n.a.

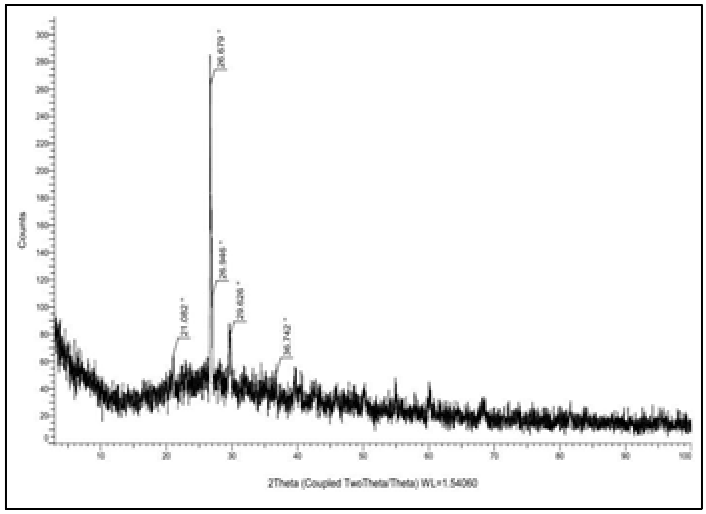

Fig 3: XRD for NaOH

Table 2: Peak List (H3PO4) XRD

Index	Angle	d Value	Net Intensity	Gross Intensity	Rel. Intensity	FWHM	h,k,l
11	55.495 °	1.65452 Å	14.7	32.2	3.0%	0.317	n.a.
7	42.584 °	2.12132 Å	17.0	37.0	3.5%	0.172	n.a.
8	45.898 °	1.97558 Å	19.7	38.6	4.0%	0.268	n.a.
16	94.557 °	1.04851 Å	21.6	30.2	4.4%	0.134	n.a.
10	55.021 °	1.66763 Å	22.3	39.2	4.5%	0.101	n.a.
6	39.584 °	2.27492 Å	23.9	43.0	4.8%	0.253	n.a.
13	67.852 °	1.38016 Å	31.4	45.9	6.4%	0.160	n.a.
12	60.087 °	1.53858 Å	36.0	49.8	7.3%	0.224	n.a.
14	68.323 °	1.37180 Å	36.4	51.5	7.4%	0.267	n.a.
15	87.383 °	1.11512 Å	39.8	49.3	8.1%	0.041	n.a.
5	36.702 °	2.44664 Å	59.0	79.6	12.0%	0.191	n.a.
9	50.280 °	1.81318 Å	70.4	87.1	14.3%	0.134	n.a.
1	20.920 °	4.24286 Å	81.4	123	16.5%	0.149	n.a.
4	27.847 °	3.20118 Å	114	149	23.2%	0.072	n.a.
3	27.402 °	3.25216 Å	164	201	33.2%	0.127	n.a.
2	26.820 °	3.32146 Å	493	532	100.0%	0.171	n.a.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2455

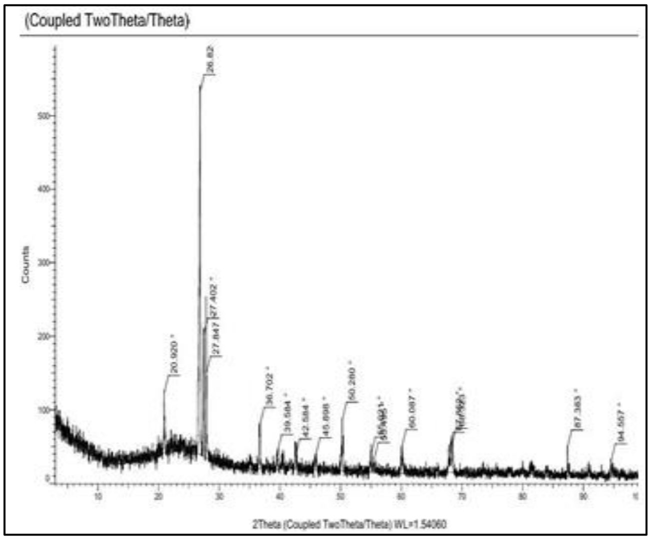

Fig 4: XRD for H3PO4

Table 3: Concentrated Solution vs Absorbance

Concentration (in ppm)	Absorbance
2	0.068
4	0.34
6	0.587
8	0.823
10	1.031

➢ *UV Spectroscopy*

An analytical technique called UV-vis spectroscopy determines how much of various visible and ultraviolet light wavelengths a sample transmits or absorbs. The methylene blue absorption curve was plotted in the first stage. To determine the wavelength that the methylene blue solution absorbs, a full methylene blue solution absorbs, a full wavelength scan was carried out. The maximal absorbance was measured at 668 nm, thus samples will be further examined at this wavelength. Three samples of 4, 8, and 12 ppm of methylene blue were created from a stock solution with 1000 ppm of the dye

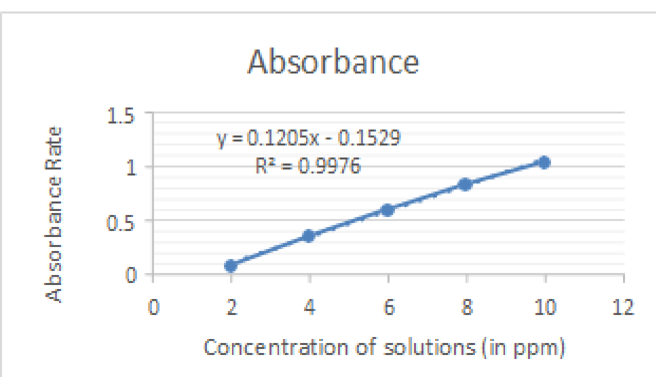

Fig 5: Standard Curve

Now again the dye removal adsorption process was conducted at same ppm solutions of 2ppm,4ppm,6ppm,8ppm and their filterate is collected and the adsorption capacity was observed in uv-spectrometer. About 10 ml sample was taken and about 0.2 gm of activated carbon was put and stirrer for about 20-30 min and then it is filtered and the filterate is checked for absorption. The concentration of dye absorbed was calculated using the equation of standard curve to know that how much mg of dye is adsorbed from the adsorbent.

The data is calculated through equation to know the adsorption capacity:

Table 4: Adsorption Capacity of Activated carbon

Concentration (in ppm)	Mg of Solute Absorbed /0.2 Gm of Absorbent
2	0.0057
4	0.0174
6	0.0292
8	0.0389
10	0.0472

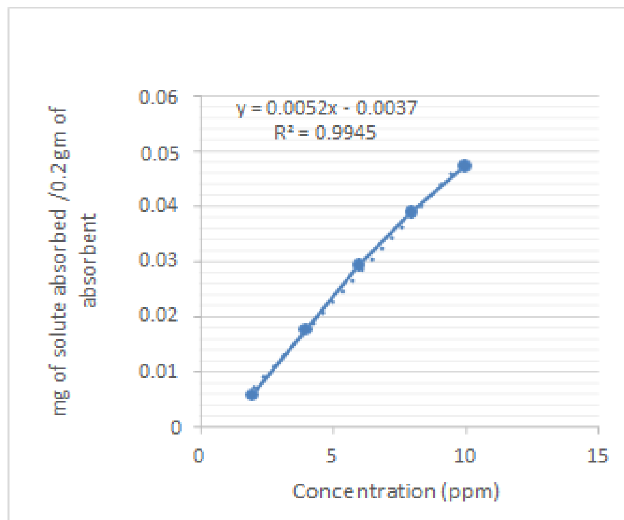

Fig 6: Plot for Adsorption Capacity

IV. CONCLUSION

This study successfully demonstrated the conversion of cow dung (CD) into porous biochar using microwave pyrolysis wherein we chemically activate it for enhancing its properties for using it as an absorbent for the application of dye removal. We also obtain the standard curve for the different concentrations using uv-spectroscopy. Using it as an adsorbent we firstly do the analysis by SEM and XRD. SEM analysis is done to reveal information about the sample including texture, chemical composition, crystalline structure and orientation of sample and XRD is done to study crystal structure and atomic structure. Our findings highlight the potential of CD as a sustainable feedstock for biochar

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2455

production. This approach offers a dual benefit: waste management of cow dung and creation of a valuablematerial with potential applications in dye removal.

The findings of this research project highlight several key points:

- *Efficient Utilization of Agricultural Waste*

By converting cow dung into porous biochar, the study effectively demonstrates the efficient utilization of agricultural waste material that would otherwise contribute to environmental pollution. This sustainable approach not only helps mitigate waste management issues but also contributes to resource conservation and environmental sustainability.

- *Adsorption Capacity for Dye Removal*

The prepared porous biochar exhibits significant adsorption capacity for dye removal from aqueous solutions. The high surface area and porous structure of the biochar provide ample active sites for the adsorption of dye molecules, leading to efficient removal and remediation of dye-contaminated water.

- *Potential for Water Treatment Applications*

The results suggest that porous biochar derived from cow dung holds great potential for various water treatment applications, particularly in the removal of dye pollutants from industrial effluents and wastewater. Its effectiveness in dye removal underscores its utility as a low-cost and sustainable adsorbent for environmental remediation efforts.(kuo, 2023)

- *Optimization and Future Research Directions*

Further optimization of the preparation process and activation methods could enhance the adsorption properties and performance of porous biochar for dye removal. Additionally, future research could explore the application of biochar-based composites or hybrid materials for synergistic effects in dye adsorption and removal efficiency.

- *Implications for Sustainable Development*

The study contributes to the growing body of research on sustainable materials and waste-to-resource conversion strategies. By highlighting the potential of cow dung-derived biochar for environmental applications, this research underscores the importance of sustainable technologies in addressing global environmental challenges while promoting sustainable development goals.

- *Economic Viability and Scalability*

The utilization of cow dung as a precursor for biochar production offers economic advantages due to its abundance and low cost compared to other feedstock materials. The scalability of the process further enhances its potential for large-scale implementation, making it a viable solution for addressing water pollution challenges in various industrial sectors.

- *Environmental Benefits*

Beyond its application in dye removal, porous biochar derived from cow dung has broader environmental benefits. Its incorporation into soil can improve soil fertility, enhance carbon sequestration, and promote sustainable agriculture practices. Additionally, the reduction of dye pollutants in water bodies contributes to ecosystem preservation and biodiversity conservation.

- *Education &Awareness*

Educating the public about the benefits of biochar and sustainable waste management practices is essential for driving societal acceptance and adoption of these technologies. Outreach programs, educational campaigns, and knowledge-sharing initiatives can raise awareness and build capacity for implementing biochar-based solutions at local, regional, and global scales.

The research on porous biochar prepared from cow dung for dye removal represents a significant contribution to the field of sustainable materials and environmental remediation. By harnessing the potential of agricultural waste streams, this study offers a practical and environmentally sound approach to addressing water pollution challenges while promoting sustainable development and resource conservation. Continued research, collaboration, and innovation are essential for unlocking the full potential of biochar-based solutions in achieving environmental sustainability goals.

REFERENCES

[1]. Yang, Q.; Li, C.; Li, H.; Li, Y.; Yu, N. Degradation of Synthetic Reactive Azo Dyes and Treatment of Textile Wastewater by a Fungi Consortium Reactor. Biochem. Eng. J. 2009, 43, 225–230.

[2]. Papinutti, L.; Nora, M.; Flavia, F. Removal and Degradation of the Fungicide Dye Malachite Green from Aqueous Solution Using the System Wheat Bran–Fomes Sclerodermeus. Enzyme Microb. Technol. 2006, 39, 848–853.

[3]. Hameed, B. H.; Ahmad, A. A. Batch Adsorption of Methylene Blue from Aqueous Solution by Garlic Peel, an Agricultural Waste Biomass. J. Hazard. Mater. 2009, 164, 870–875. [4]. Xu, R. K.; Xiao, S. C.; Yuan, J. H.; Zhao, A. Z. Adsorption of Methyl Violet from Aqueous Solutions by the Biochars Derived from Crop Residues. Bioresour. Technol. 2011, 102, 10293–10298.

[4]. Qu, Y.; Shi, S.; Ma, F.; Yan, B. Decolorization of Reactive Dark Blue KR by the Synergism of Fungus and Bacterium Using Response Surface Methodology. Bioresour. Technol. 2010, 101, 8016–8023.

[5]. Wu, Y.; Zhang, L.; Gao, C.; Ma, J.; Ma, X.; Han, R. Adsorption of Copper Ions and Methylene Blue in a Single and Binary System on Wheat Straw. J. Chem. Eng. Data. 2009, 54, 3229–3234.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/IJISRT24APR2455

[6]. Zhao, M.; Tang, Z.; Liu, P. Removal of Methylene Blue from Aqueous Solution with Silica Nano-Sheets Derived from Vermiculite. J. Hazard. Mater. 2008, 158, 43–51
[7]. Esmaeili, H.; Foroutan, R. Types of Sewages and Reviews of Wastes Biological Filtration Methods. Int. J. Biol. Pharm. All. Sci. 2015, 4, 611– 619.
[8]. Sarvestani, F. S.; Esmaeili, H.; Ramavandi, B. Modification of Sargassum angustifolium by Molybdate during a Facile Cultivation for High- Rate Phosphate Removal from Wastewater: Structural Characterization and Adsorptive Behavior. Biotech. 2016, 6, 251.
[9]. Foroutan, R.; Esmaeili, H.; Abbasi, M.; Rezakazemi, M.; Mesbah, M. Adsorption Behavior of Cu (II) and Co (II) Using Chemically Modified Marine Algae. Environ. Technol. 2017, 1–9.
[10]. A.Y. Lehi & A. Akbari, 2017. Membrane Capsules with Hierarchical Mg(OH)2 Nanostructures as Novel Adsorbents for Dyeing Wastewater Treatment in Carpet Industries. J. Taiwan Inst. Chem. Eng., 70, pp. 391–400.
[11]. A.R. Khataee, A. Movafeghi, S. Torbati, S.Y. SalehiLisar & M. Zarei, 2012. Phytoremediation Potential of Duckweed (Lemna Minor L.) In Degradation of C.I. Acid Blue 92: Artificial Neural Network Modelling. Ecotoxicol. Environ. Saf., 80, pp. 291–298.
[12]. L. Fan, Y. Zhou, W. Yang, G. Chen & F. Yang, 2008. Electrochemical Degradation of Aqueous Solution of Amaranth Azo Dye on ACF under Potentiostatic Model. Dyes Pigments, 76, pp. 440–446. Science Letters 96
[13]. J.S. Wu, C.H. Liu, K.H. Chu & S.Y. Suen, 2008. Removal of Cationic Dye Methyl Violet 2B from Water by Cation Exchange Membranes. J. Membr. Sci., 309, pp. 239–245.
[14]. Y.S. Woo, M. Rafatullah, A.F.M. Al-Karkhi & T.T. Tow, 2013. Removal of Terasil Red R Dye by using Fenton Oxidation: A Statistical Analysis. Desal. Water Treat., 53, pp. 1–9.
[15]. A.H. Jawad, A.F.M. Alkarkhi & N.S.A. Mubarak, 2015. Photocatalytic Decolorization of Methylene Blue by an Immobilized TiO2 Film under Visible Light Irradiation: Optimization using Response Surface Methodology (RSM). Desalin. Water Treat., 56, pp. 161–172.
[16]. Lima, I. M., et al. "Characterization of biochar from dairy-manure gasification and its evaluation as a soil amendment." Biomass and Bioenergy 46 (2012): 370-377.
[17]. Mašek, O., et al. "Biochar pyrolyzed at two temperatures affects Escherichia coli transport through a sandy soil." Journal of Environmental Quality 40.4 (2011): 1138-1149.
[18]. Martinsen, V., et al. "Potential of biochar for climate change mitigation in Norway: Modelling approach and results." Biomass and Bioenergy 77 (2015): 33-47.
[19]. Mekonnen, T., et al. "Biochar made from agro-industrial waste for adsorption of reactive dye from aqueous solution." Sustainable Environment Research 28.1 (2018): 19-24.
[20]. Mukome, F. N. D., et al. "Biochar from cow manure and straw: Effects of aging on surface properties and sorption mechanisms." The Royal Society of Chemistry Advances 2.9 (2012): 8597-8606.
[21]. Nigussie, A., et al. "Biochar for soil fertility and natural resource management." Biochar for Environmental Management: Science, Technology and Implementation 2 (2015): 161-198.
[22]. Oliveira, F. J., et al. "Biochar from biomass and waste." Advances in Bioenergy 8 (2017): 175-212.
[23]. Puga, A. P., et al. "Biochar application to a contaminated soil reduces the availability and plant uptake of zinc, lead and cadmium." Journal of Environmental Management 133 (2014): 243-253. [24]. Qambrani, N. A., et al.
[24]. "Biochar properties and eco-friendly applications for climate change mitigation, waste management, and wastewater treatment: A review." Renewable and Sustainable Energy Reviews 119 (2020): 109579.
[25]. Rashad, M., et al. "The mechanism of organic dye adsorption onto low-cost adsorbents: A review." Environmental Science and Pollution Research 22.12 (2015): 8148-8167.
[26]. Ravindran, B., et al. "Sorption of reactive dyes from aqueous solution by acid activated low cost carbon prepared from Euphorbia antiquorum L." Journal of Hazardous Materials 151.1 (2008): 32-40.
[27]. Rondon, M. A., et al. "Biochar as a strategy to sequester carbon and increase yield in durum wheat." Soil Science Society of America Journal 70.5 (2006): 1930-1935.
[28]. Tan, X., et al. "Elucidating adsorption mechanisms of methylene blue onto biochar." Bioresource Technology 124 (2012): 489-495.