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Review Article

An Integrated Approach of ANN and CFD for Predicting and Modelling the Adsorptive Removal of Methylene Blue Dye Using Sandbox Seed as Adsorbent: A Review

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Abstract

The relevance application of dye cannot be overemphasized in our vicinity today, ranging from paintings, textiles, artistic purposes. Also, several other industrial applications including the cosmetics, leather, paper and even food industry. Notwithstanding its wide application, research has shown that the production of waste water containing synthetic dyes are deleterious to the environment and the ecosystem and therefore needs to be removed for the safety of the ecosystem. Several techniques like reverse osmosis, membrane filtration and coagulation can be used for removal of dyes. Some of these methods, despite their efficiency in wastewater treatment, they are expensive and sometimes complex to set up, therefore there is need for cheaper, affordable and simple method of wastewater treatment. Adsorption, mostly with waste biomass has proven to be a good and inexpensive method of dye removal from waste water. Therefore, this article reviewed adsorption of methylene blue dye unto sandbox seed biosorbent in a fixed bed continuous adsorption column. This review shows that there is still more to be done in terms of combining two or more different approaches in predicting and modelling adsorption of methylene blue removal from effluent water in order to obtain optimum result from treated water.

Keywords

Adsorption, Computational Fluid Dynamics, Artificial Neural Network, Dye

1. Introduction

The deleterious effect of the contamination of water body by synthetic dyes has generated controversial environmental concerns over the years. The necessity of developing an efficient and sustainable dye removal techniques is driven by such industries as textile manufacturing and wastewater treatment industries which are key contributors to discharge of dye containing effluences [1, 2]. Several researchers have studied the effect of industrial effluence on some water bodies in Nigeria [3, 4] In response to this challenge, adsorption has emerged as a cheaper, versatile and effective approach to waste water treatment [5, 6].

The abundance, eco-friendly and low cost of some plant-based materials and agricultural waste as adsorbents have attracted the attention of researchers. Several researchers

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have used different parts of different plant as adsorbent for adsorption of dyes [7-9]. Sandbox Seed, a type of natural adsorbent, has shown potential for the adsorption of Methylene Blue dye as a result of its porosity and high surface area, making it useful for adsorption applications. However, to fully harness the adsorption capabilities of Sandbox Seed and optimize the removal process, a deeper understanding of the adsorption mechanism and predictive modeling is essential [10, 11]. This study reviews the exiting research in artificial neural network and computational fluid dynamics as an approach to carrying out adsorption studies.

2. Adsorption

Different methods can be used to remove dye compounds from aqueous solutions, some methods used in dye removal include: chemical oxidation [12], coagulation [13], membrane separation process [14, 15], exchange of ions [16, 17] electrochemical [18] and aerobic and anaerobic microbial degradation [19].

Saleh [20] defined adsorption as a process in which adsorbate from gas or liquid phase is attached to the surface of a solid phase (adsorbent) when the adsorbate is brought in contact with the solid phase. Any substance that has undergone adsorption on the surface is considered an adsorbate [21]. There are different types of water pollutants found in our environment today. These can be classified into the following major categories: (1) organic pollutant, (2) inorganic pollutant, (3) sediments [22], (4) thermal pollution, and (5) radioactive pollutants [23]. These pollutants are hazardous to mankind, aquatic life and other ecological constitutions [24].

The adsorbent is broadly divided into three classes; Synthetic adsorbent, Natural adsorbent and Semi-synthetic adsorbent. [25] Industrial adsorbent is also classified into three types; oxygen-containing adsorbent, polymer-based adsorbent and carbon-based adsorbent according to their constitution [26-28].

Several analytical methods are used to identify the adsorbent's properties, including Fourier transform infrared spectroscopy (FT-IR), which determine the chemical composition through the functional group; scanning electron microscopy (SEM), which looks at the adsorbent's morphology and X-ray diffraction (XRD), which gives information on the material's crystallographic structure. Other methods include porosity, pore diameter, pore volume, and surface area analysis [29-32].

There are various types of techniques employed to ensure the contact of adsorbate and adsorbent for adsorption to occur they are; Batch adsorption technique, continuous moving bed, continuous fixed bed (up-flow or downflow), continuous fluidize bed and pulsed bed or a continuous process. Their advantages and disadvantages are summarized in Table 4 [25]. Also, Table 4 reveals that fixed bed column is industrially feasible for removal of various contaminations from synthetic as well as real wastewater, but the most frequently used are batch adsorption and continuous fixed bed adsorption. [33, 8]. Batch adsorption experiments are mostly carried out at constant volume where a known quantity of the adsorbent measured by weight is being introduced into a known quantity of the adsorbate solution, at constant agitation for a fixed amount of time, after which the adsorbent is being filtered out. This method will not favour the treatment of waste water under constant flow, since it is being carried out in batches [7]. Although batch adsorption techniques offer highly useful details for the design of industrial-scale processes, it might not be an efficient means to handle high-flow rate treatments on an industrial scale [10, 11, 34].

In fixed bed adsorption, the solution containing the adsorbate is made to flow through a porous bed of the adsorbent at a constant flowrate to enable the adsorption of the adsorbate unto the adsorbent, Adsorption in a fixed bed column can be used continuously under high effluent flow rates, making it suitable for industrial or practical application, many pollution control processes have applied this method [10, 11, 35].

However, to properly design and operate fixed-bed filters for practical applications, a proper study of the equilibrium and dynamic adsorption properties are necessary to understand the adsorption process. The adsorption equilibrium data for a fixed bed adsorption can be quantitatively interpreted using a wide range of models. However, adsorption in a fixed bed column is a dynamic, non-steady process, which is more difficult to interpret, and the process depends on the possible interaction of several variables [36].

3. Process Parameter for Column Study

To study the adsorption characteristics of an adsorbent in a continuous column system some of the parameters that affect the characteristics of the adsorption process needs to be understood. The process parameters that affect the adsorption behaviour of adsorbate in a column adsorption system include flow rate of adsorbate in the column [37], the initial adsorbate concentration [38], bed height of the column, particle size of the adsorbent, pH of the adsorbate [39] and temperature of the system [38]. These factors are crucial and helpful for assessing the effectiveness of an adsorbent in a continuous effluent treatment process, whether it be on a pilot or industrial scale [40, 25]). Table 3 shows a summary of adsorption studies carried out using fixed bed adsorption techniques and their results.

The performance of a fixed-bed column can be predicted through a mathematical modeling approach of breakthrough curves [41, 42]. Among the most used mathematical models to describe the dynamic behavior of pollutant removal in a fixed-bed column are the Bohart-Adams, Thomas, Yoon-Nelson, Wang, Wolborska, and modified dose-response models [7, 43, 44]. The model equations for these models are presented in Table 1.

Table 1. Column adsorption models.

Column adsorption model	Model equation
Thomas model (TM)	$ln\ \left(\frac{C_i}{C}-1\right)=\frac{K_{TH}q_Fm}{Q}-K_{TH}C_it$
Bed depth service time model (BDST)	$t=\frac{N_O}{C_Ou}Z-\frac{1}{kc_o}ln\left(\frac{C}{C_i}-1\right)$
Adam and Bohart model (ABM)	$ln\ \left(\frac{C_i}{C}-1\right)=\frac{K_Bq_mH}{u}-K_BC_it$
Yoon–Nelson model (YNM)	$ln\ \left(\frac{C_i}{C}-1\right)=K_{YN}\tau-K_{YN}t$
Clark model (CM)	$\frac{C}{C_i}=\left(\frac{1}{1+Ae^{-rt}}\right)^{1/(n-1)}$
Wolborska model (WM)	$ln\ \left(\frac{C}{C_i}\right)=\frac{\beta_lC_l\varepsilon}{\rho q_F}-\frac{\beta_lH}{u}$
Modifed dose response model (MDRM)	$\frac{C}{C_i}=1-\frac{1}{1-\left(\frac{C_iQ_t}{q_Fm}\right)^{a'}}$
Wang model	$t=\tau+\frac{1}{K_W}\ ln\ \left(\frac{X}{1-X}\right)$

4. Dye

Dyes are the coloured aromatic organic compounds that absorb light and impart color to the visible region [45, 46]. More than 100,000 commercial dyes have been reported worldwide [47], Methylene blue is a basic thiazine dye, tetramethylthionine chloride, is regarded as the first synthetic drug ever administered to a human. [48]. Methylene blue is an odorless dark green crystalline powder at room temperature which dissolves in water to yield a blue-coloured solution [49, 50]. Its first application in medicine were as an intestinal and urinary antiseptic, as a weak antimalarial, and in 1933 as treatment for aniline induced methemoglobinemia (MetHB) [51].

Table 2. Review of adsorption models for the removal of methylene blue dye.

S/n	Work done	Adsorbent/adsorbate	Findings	Modeling/optimization tool	Method of adsorption	author
1	Application of RSM for Methylene Blue dye removal from aqueous solution using low-cost adsorbent	Charred partheni-um/methylene blue dye	93.4% removal of methylene blue was obtained at 25 mg/L initial concentration, 0.2 g of CP, pH of 7 and temperature of 35°C. also found out that pH has the greatest influence on dye recovery from spent adsorbent	RSM	Batch adsorption	[33]
3	Application of RSM for Bioremoval of Methylene Blue Dye from Industrial Wastewater onto Sustainable Walnut Shell (Juglans regia) Biomass	Walnut shell bio-mass/methylene blue dye	Maximum Methylene blue die removal of (97.70%) was obtained with a 30 mg/L, 1.5 gm of biomass, pH of 6, and for 60 min at 25°C.	RSM	Batch adsorption	[8]
4	Modeling of adsorption of Methylene Blue dye on Ho-CaWO4 nanoparticles using RSM	Ho-CaWO4 nanoparticles/methylene blue dye	the RSM model was more acceptable since it has the lowest RMSE and AAD compared to the ANN model. Optimum MB removal of 71.17% was obtained at pH of 2.03, contact time of 15.16 min,	ANN and RSM	Batch adsorption	[52]

S/n	Work done	Adsorbent/adsorbate	Findings	Modeling/optimization tool	Method of adsorption	author
	and ANN techniques		Ho-CaWO4 nanoparticles dose of 1.91 g/L, and MB concentration of 100.65 mg/L. Maximum adsorption capacity (qm) of 103.09 mg/g was obtained.			
5	ANN modeling of adsorption of methylene blue by NaOH-modified rice husk in a fixed-bed column system	Rice husk/methylene blue	Results show that with increasing bed height and decreasing flow rate, the breakthrough time was delayed. the ANN model is the most suitable model to describe the fixed bed adsorption of MB by modified rice husk	ANN	Fixed bed column adsorption system	[9]
6	Investigation of an Adsorptive Indigo Carmine Dye Removal via Packed Bed Column: Experiments and Computational Fluid Dynamics Simulation	graphene nanoadsorbent/Indigo Carmine Dye	Their result shows that High bed depth, low flow rate and high initial dye concentration increased the adsorption capacity of the adsorbent. Also, the optimum removal efficiency of the adsorbate was achieved to be 67% at flow rate, bed depth, and concentration of 1 ml/min, 28 cm and 10 ppm, respectively	CFD	Packed bed column and batch adsorption system	[53]
7	Adsorptive removal of methylene blue dye from aqueous streams using photocatalytic CuBTC/ZnO chitosan composites	CuBTC/ZnO chitosan composite/ Methylene blue dye	Their result shows that the pseudo second order and Langmuir models were the best fit for the adsorption process, at adsorbent dosage of 1.6 g/L, and 90 min a removal efficiency of 98.75% was achieved		Batch process	[54]
8	Prediction of methyl orange dye (MO) adsorption using activated carbon with an artificial neural network optimization modeling	Date seed activated carbon/Methylene blue dye	The system was found to follow the pseudo second order kinetics at R2 value of 0.9973. Also, it was discovered that the Langmuir model performed better with an R2 value of0.9902	ANN	Batch adsorption	[55]
9	use of RSM and ANN approach for methylene blue removal by adsorption onto water hyacinth	Water hyacinth / methylene blue	Color removal of 96.649% was obtained experimentally at the optimized condition. A comparison between the experimental data and model results shows a high R^2 value (R^2 RSM = 0.99 and R^2 ANN = 0.98) and showed that the two models predicted MB removal indicating that WH is a good adsorbent.	ANN, RSM	Batch adsorption	[56]

MB = Methylene blue, ANN = artificial neural network, RSM = response surface methodology

Table 3. Review of adsorption models using computational fluid dynamics approach.

S/n	Work done	Adsorbent/adsorbate	Parameters studied	Findings	Software used	author
1	Computational Fluid Dynamics Analysis of Mercury Adsorption by Inverse-Vulcanized Porous Sulfur Co-	porous sulfur copolymers	mercury-ion concentrations, volumetric flow rate, temperature, and adsorbent thick-	The CFD model results are validated with the experimental results at fixed and varied operational conditions. The inverse-vulcanized sulfur present high porosity of (59.09%), less	ANSYS FLUENT	[54]

S/n	Work done	Adsorbent/adsorbate	Parameters studied	Findings	Software used	author
	polymers		ness	density (0.53 g/cm3), and smaller particle size (20−50 μm). Therefore, it exhibits high adsorption efficiency in the case of experimental (244 μg/g) and CFD simulations (249 μg/g) compared to other samples.		
2	Investigation of an Adsorptive Indigo Carmine Dye Removal via Packed Bed Column: Experiments and Computational Fluid Dynamics Simulation	graphene nanoadsorbent/Indigo Carmine Dye	The effect of flow rate, initial concentration, bed depth and reusability of the adsorbent were studied	Their result shows that High bed depth, low flow rate and high initial dye concentration were the potential parameters for the high adsorption capacity. The removal efficiency of indigo carmine dye was achieved to be 67% as flow rate, bed depth, and concentration of 1 ml/min, 28 cm and 10 ppm, respectively	CFD (using comsol Multiphysics)	[57]
3	Adsorption of methylene blue dye from the aqueous solution via bio-adsorption in the inverse fluidized-bed adsorption column using the torrefied rice husk	torrefied rice husk/methylene blue dye		Inverse fluidized bed bio-adsorption column has increased the overall methylene blue removal to 84% at saturation time of 95 min continuous adsorption, breakthrough time of 22 min and adsorptive capacity of 6.82 mg/g which is higher than those obtained from fixed bed adsorption column	-	[7]
4	Combination of adsorption-diffusion model with CFD for study of desulfurization in fixed bed	Ag-TiO2-SiO2) / (4,6-DMDBT)	feed concentration, feed rate and column height	The results of their simulation demonstrated that the simulated results aren't affected by the mesh number. Also, the mass transfer rate increases with increasing feed concentration at the beginning due to the higher driving force at higher feed concentration	Fluent software integrated in Ansys	[58]
5	Modelling and simulation of fixed bed adsorption column using integrated CFD approach	CO2/CH4 and CO2 moisture	Effect of feed velocity, bed porosity, feed concentration and temperature profile were studied	The simulated results were compared with experimental data and found to give a good agreement with error less than 2.5%. their result also showed that higher feed velocity tends to give a reduction in removal efficiency, also, the influence of hydrodynamics is more dominant as compared to the effect of mass transfer		[59]
6	Isotherm and computational fluid dynamics analysis of nickel ion adsorption from aqueous solution using activated carbon	Activated carbon/ nickel	Adsorbent amount, feed flow rate, Ni2+ concentration, temperature, and solution pH on the removal efficiency as well as breakthrough and saturation	The result showed that > 99.0% removal of Ni+2 was obtained at the optimum conditions which are feed flow rate 5 mL/min, pH = 7.0, initial concentration = 5 mL/L, Temperature = 35 °C, and bed height 12 cm for the first 185 (± 5) minutes.	Comsol multiphysics	[60]

S/n	Work done	Adsorbent/adsorbate	Parameters studied	Findings	Software used	author
			points.			
7	A Combined CFD-RSM Approach for Simulation and Optimization of Arsenic Removal in a Fixed Bed Adsorption Column	Iron ore/ arsenic	adsorbent bed depth, the feed flow rate, and the initial Arsenic concentration (conc.). response for RSM model are removal efficiency and the bed saturation time	The RSM predicted values were closed to the CFD measurement. Feed flowrate and bed depth were found to be more significant. Optimum conditions were found to be at bed height of 80 cm, the initial Arsenic concentration of 2.7 mmol/m3, and the feed flow rate of 1 L/min	CFD (Comsol Multiphysics) and RSM (Design expert 8)	[61]
8	Modeling and computational fluid dynamic simulation of acetaminophen adsorption using sugarcane bagasse	Sugarcane bagasse/ acetaminophen	Three experimental tests were carried out at 2.5 mL/min of flow rate, 57 mg/L of ACT concentration, and bed heights of 23, 33, and 43 cm.	The predicted model agreed with the experimental at r2 value of >0.91. the maximum error between experimental and predicted points was 7.03%.	COMSOL Multiphysics V5.4	[41]

Table 4. *Features and limitation of various sorption processes [25, 62-64].*

Particular	Batch adsorption	Continuous fixed bed sorption	Continuous moving bed sorption	Continuous fixed bed sorption	Pulsed bed sorption
Introduction	Adsorbent and adsorbate are well mixed in diluted solution at constant volume in well mixed system	Fixed bed system consist of an adsorbent in which adsorbate is continuously flowing through a bed of adsorbent at constant rate	CMBS is steady state system where both adsorbent and adsorbate are in motion, and bed of adsorbent section remains constant but not in equal condition.	In this sorption, adsorbate is in contact with fluidized bed of adsorbent with sufficient or insufficient flow	In pulsed bed sorption, adsorbate is contacted with same adsorbent in bed, until desired results are not achieved.
Features	Very easy and cheap technique. Most often researchers are using this technique to analyze feasibility of adsorbent adsorbate system	Very easy and cheap technique Used for higher quality of waste water having high pollution load. Also used for industrial purpose, because the adsorbate is continuously in contact with a given quantity of fresh adsorbent in fixed bed column system	Complicated and very expensive technique. As adsorbent is continuously replaced and fresh adsorbent is constantly contact with adsorbate.	Complicated and very expensive technique. Used for high quantity of waste water having high pollution load. Applicable for industries because it allows rapid mixing of adsorbent adsorbate since the flow is continuous and automated with controlled operation/easy handling	Very easy and cheap technique. It is very easily controlled and automatically operated system. Also it required lower dosage of adsorbent because the adsorbents were kept for regeneration after saturation.

Particular	Batch adsorption	Continuous fixed bed sorption	Continuous moving bed sorption	Continuous fixed bed sorption	Pulsed bed sorption
Disadvantages	Used for small quantity of waste water having minimum pollution load, therefore hardly found in industrial application. Adsorbent is removed from the system by simple filtration method	The problems here is adsorbent attrition, feed channeling, and non – uniform flow of adsorbent particles Forceful interaction is conducted here to reduce space and time. therefore, difficult to carry out a priori design and optimization of fixed bed columns without a quantitative approach	The large amount of adsorbents is required to complete sorption Continuous regeneration of adsorbent storage is essential	Flow of adsorbate is not measured with large deviation from plug flow and bubbling or feed channeling, which leads to insufficient contact of adsorbent adsorbate The rapid mixing of adsorbent adsorbate system leads to non-uniform residence time	Used for small quantity of waste water having minimum pollution load especially lower suspected solid Adsorbent is not unfilled in normal operation

Due to the toxicity of methylene blue dye, it is harmful to human health at certain concentration [65]. It is toxic, carcinogenic, non-biodegradable and can cause a serious threat to human health and destructive effects on the environment [66-68]. Methylene blue dye caused several health hazards like nausea, diarrhea, vomiting, cyanosis, shock, gastritis, jaundice, blue baby syndrome, and tachycardia, Necrosis [69-72]. Methylene Blue contacts with skin may result in skin redness and itching [73].

5. Computational fluid dynamics

The modeling of kinetic and equilibrium adsorption phenomena in the fixed bed adsorption column has received a lot of interest and attention in an effort to reduce the high cost of the experimental setup for commercial scaleup. Many researchers have employed a number of well-known mass transfer models for adsorption beds, including the linear driving force (LDF) and pore diffusion model. etc. Alongside the notable advancements in computational resources and codes, there has been a great deal of attention recently in connecting engineering models with rigorous simulation tools. Simulation techniques may offer a compelling substitute for expensive and time-consuming experimentation. Computational fluid dynamics (CFD) simulation is suitable when the fluid dynamics determines the process performance. It has been proposed as a suitable tool for modelling and simulation of hydrodynamics, heat and mass transfer phenomenon for the purpose of designing and optimization of process equipment [74, 59] Computational modeling has become an essential part of science and engineering. Recent years have seen the development of software that can replicate a wide range of physical and chemical processes that occur in pilot plants, laboratories, and industrial settings. The use of COMSOL Multiphysics allows profitable savings in operational processes and predicts the behavior of the breakthrough curve by considering the main phenomena in a fixed-bed column [75].

6. Comsol Multiphysics TM

Comsol Multiphysics

Comsol Multiphysics is a commercial PDE that makes it possible to compute multiple physics at once. For instance, models of heat transfer and fluid momentum transfer can be created for the same object and solved simultaneously. Comsol Multiphysics has been adopted for undergraduate coursed by educators in recent time in areas of heat transfer [76], Machine Design and several researches by undergraduates [77].

Comsol Multiphysics possess the ability to model adsorption bed using adsorption mechanism parameter and transport equations, to obtain adsorption behavior for various operational parameters (inlet concentration, flow rate, and inlet temperature) and to optimize operation conditions [78].

Several researchers have carried out adsorption studies in both batch and column adsorption using comsol Multiphysics, Response surface methodology and artificial neural network some of them are summarized in table 2. Some researchers applied CFD techniques to study fin thickness and fin height of adsorbent, and their result showed that decreasing the fin thickness increased the water uptake by up to 8% and decreased the fin height from 30 mm to 20 mm, which resulted in an increase of the water uptake up to 17% [79]. The CFD technique was also used to investigate the effect of plate type on the adsorption bed performance. The results showed that the copper plate improved the water uptake up to 9%. The copper plate decreased the temperature of the adsorption bed up to 11% more than the aluminum plate [79].

Also, Yuma et al., [80] used CFD approach to the model adsorption rate prediction for Granular Activated Carbon Packed Bed, the developed model predicts the adsorption performance for differently shaped filters, made of the same material, using the predicted parameters. The researcher proposed a CFD modelling method that enables the prediction of the adsorption rate of activated carbon and filtered adsorption performance even in solution with 100 lg/L or less. Their proposed method aids the adsorption rate and adsorption performance predictions for differently shaped filter with sample filtration test using single column.

Ali, et al., [81]. Studied adsorption isotherms and thermodynamic Study of Cu (II) and Ni (II) removal using commercial zinc oxide nanoparticle. The researchers showed that the removal of cu (II) and Ni (II) using ZnO nanoparticle as the adsorbent followed the Freundlich and Halsey isotherm and that it fits well with the experimental data at a high R^2 value, with maximum Ni (II) and Cu(II) removal of above 96.03% and 96.45% respectively. Also, their thermodynamic studies showed that the adsorption process is exothermic, spontaneous and less random when metal ions overlap with the commercial zinc oxide nanoparticles. They also attribute the higher percentage removal at higher dosage value of ZnO obtained in their work to an increased active site of the adsorbent.

Ali et al., [82]. Studied adsorption technique for the removal of heavy metals from wastewater using low-cost natural adsorbent. The researcher studied the effect of some hydraulic parameters like contact time, length of pipe, pressure and flow discharge, with environmental parameters like pH, TSS, TDS and electrical conductivity in a continuous flow system. Their adsorbent was treated and activated by ozonation to increase porosity. From their study, the most effective removal efficiency of Zn +2 was 95% recorded at pH of 7, flow rate of 20 l/hr for 5 hrs, while the higher removal efficiency of 96.67% of Fe+2 occurred at pH 6, 20 l/hr, and 5 hr.

7. Artificial Neural network (ANN)

Artificial Neural Networks (ANNs) are computational models inspired by the functioning of the human brain's neural networks [83-85]. They possess the ability to learn from experience, recognize patterns, and effectively model complex systems and non-linear problems [86]. ANNs consist of interconnected nodes (neurons) organized into layers, including input, hidden, and output layers [87]. During the training process, the weights of connections between neurons are iteratively adjusted using optimization algorithms, such as backpropagation, allowing the network to effectively learn and generalize from known input-output pairs [88]. In the context of heavy metals and dye biosorption, ANNs have become essential tools due to their capacity to accurately capture and predict intricate interactions between heavy metal ions and biosorbents [88]. For example, [82]) developed an ANN-based prediction model for Pb (II) biosorption using carbon micro/nanomaterials, accurately estimating the adsorption capacity of heavy metals. By analyzing extensive experimental data, ANNs can develop predictive models that provide valuable insights into biosorption capacity, kinetics, and breakthrough curves for diverse biosorbents under varying conditions [89]. This predictive capability is critical in optimizing biosorption processes, aiding researchers and engineers in evaluating the effectiveness of different biosorbents and identifying optimal operational parameters for maximum heavy metal removal [90]. Additionally, ANNs enable the exploration of the impact of factors such as pH, temperature, contact time, and competing ions on biosorption performance, facilitating the development of robust and adaptable biosorption systems [91]. While ANNs offer valuable modeling capabilities, it is also important to consider potential limitations, such as overfitting and the need for a sufficient dataset for training, to ensure accurate and reliable predictions.

8. Integrated approaches for adsorption

However, research on the combination of CFD (Computational Fluid Dynamics) simulation and artificial neural network for modelling of an adsorption processes are still very rare. Some researches that are similar to the topic of related discussion have been largely done by experts. Meiqin et al., [58], Used CFD and RSM approach for the simulation and optimization of arsenic removal in a fixed bed adsorption column. Maddodi et al., [61]. Used response surface methodology and artificial neural network for methylene blue adsorption undo water hyacinth. In their work, the ANN and RSM approach was used to predict the removal efficiency of water hyacinth on methylene blue dye, according to their result, the models predicted by both ANN and RSM showed a high correlation coefficient of 0.99 for the RSM model and 0.98 for the ANN model. This shows that the RSM model performed better than the ANN model for methylene blue adsorption using water hyacinth.

9. Conclusion

From various literature surveys, it can be concluded that the combination of ANN and CFD approach for the adsorption of methylene blue dye is still in the very infancy. This paper review various research works carried out on the adsorption of methylene blue dye removal using various techniques and adsorbent, ranging from batch and column adsorption techniques. Adsorption has been proven to be a cost effect for water purification and other application, column adsorption among other method is easier, better, simple, economical and feasible for industrial removal of various contaminants like dye, heavy metals and other waste from industrial effluents. In order to conserve resources, computational models have been used to study and improve the adsorption properties of adsorbents and also optimize their results. This review shows that there is still more to be done in terms of combining two or more different approaches in predicting and modelling adsorption of methylene blue removal from effluent water.

Abbreviations

CFD	Conputational Fluid Dynamics
ANN	Arificial Neural Network
RSM	Response Surface Methodology
MB	Methylene Blue

Conflicts of Interest

The authors declare no conflicts of interest.

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