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Review article

A review of novel methods for Diuron removal from aqueous environments

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ABSTRACT

Runoff from intensive agriculture, which contains many sources of pollutants, including herbicides, for instance, Diuron, has threatened the environment and human health. The intrusion of these toxins into water sources poses a serious challenge to human society, and the rising release of these toxins has always been of concern to water researchers. The consequences of the release of these toxins into water sources are destructive and debilitating to human life. Today, the contamination of surface water and wastewater by pesticide residues, especially from agricultural activities and pesticide factories, has grown significantly. One of the pesticides commonly applied around the world is Diuron. There are various techniques for removing Diuron, the most important of which are adsorption and advanced oxidation. This review presents the characteristics, mechanisms, and emerging methods of removing Diuron. The use of absorbents, such as sludge-derived modified biochar (SDMBC600) and bottom ash waste (BAW-200), is discussed in detail. Additionally, the main features, benefits, and limitations of new technologies like hydrodynamic cavitation are enumerated. The effectiveness of novel adsorbents in Diuron removal is also discussed.

1. Introduction

With increasing sources of pollutants and widespread distribution of various contaminants, water may become scarce in future years. They estimated that by 2050, less than 50 % of the world's population will have access to safe, clean water [1–4]. That is why scientists and researchers have been continuously engaged in exploring and researching innovative and environmentally friendly methods to minimize the adverse effects of pollutants [5–9]. Based on this, various techniques, including improving soil quality to promote pollutant absorption and using new pollutant detection equipment, have been used by researchers to protect the environment [10–14]. Pesticides are one of the major sources of contaminants in water [15,16]. Because of the high consumption of these poisons in intensive agriculture, one can say that they represent the most significant challenge for the aquatic environment [17,18]. Diuron molecule is a persistent pollutant in aquatic environments [19]. A Diuron is one of the herbicides that has received particular attention in recent decades [20]. This herbicide based on phenyl urea is one of the pesticides widely used in agriculture, particularly on sugarcane farms [21]. This toxin has entered water sources via agricultural runoff and factories producing this toxin and has been detected

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in water and wastewater treatment plants and underground waters in many parts of the world [22–24]. Its potential cellular and gene toxicity and other harms listed in various studies have led to its classification in the IRIS as one of the priority pollutants and in Group 1 [25,26]. Recently, PUHs have attracted a lot of attention due to their high biotoxicity and potentially carcinogenic properties [27]. The special attention to the harmful effects of this toxin has led to its maximum permissible concentration in the water sources of European municipalities reaching 0.1 μg/L [28]. This toxin has been identified in most rivers of more than 20 European countries at a concentration of 0.826 μg/L [29]. This important issue led to the adoption of legislation by the European Commission in 2013 to add diuron to the list of priority pollutants and revise water treatment policy to address this actual environmental hazard [30,31]. The inefficiency of conventional water purification methods and the drawbacks of many new techniques in recent decades in engineering projects have determined the ineffectiveness of many processes [32,33]. To eliminate this toxin, researchers have thus developed new advanced oxidation procedures [34]. Sometimes new adsorbents Environmentally friendly, economical and compatible adsorbents have been obtained through absorption-based methods [35,36] with exceptional efficiencies [37]. The utilization of agricultural waste and biochar from sewage sludge was one such adsorbent that became progressively more effective in eliminating this weed [38,39]. The disadvantages of chemicals as well as their high cost made methods such as hydraulic cavitation an essential prospect. In this review article, we will briefly describe the novel methods for removing a diuron from water bodies, enumerate the removal mechanisms, the efficiency of each procedure and the use of novel types of adsorbents, and mention in headings the benefits and drawbacks of the approaches.

2. Diuron removal methods

2.1. Disadvantages of conventional methods of purification

The old and common methods of removing Diuron from water include biological purification, filtration, adsorption and oxidation, which have many advantages and disadvantages depending on the method, but this review article will examine the disadvantages of these methods and the reason for the revision. In some processes and modifications of the new methodology. The author takes a closer look at the discussion of efficiency, economy, initiative and innovation. Table 1 briefly mentions the disadvantages of each method [40].

In the following, we will discuss the new methods of removing diuron related to the last decade.

2.2. Adsorption

Adsorption is a suitable physical process to remove dieresis from aquatic environments. So far, various adsorbents have been used to absorb herbicides. Adsorbents such as date shell [41], bamboo biochar [42,43], Moringa oleifera seed [44] and activated carbon [45] are such. In this review, we mention the latest adsorbents used in the removal of diuron during the last 3 years.

The application of the adsorption technique for the elimination of diuron is associated with multiple challenges. Some of the strategic challenges are.

1. Cost-effectiveness of adsorbents: the question is whether the adsorbent operated can be efficient in removing diuron. Is the performance excellent or at least good in relation to the cost? The cost of adsorbents can significantly affect the feasibility of large-scale elimination of diuron. Producing and procuring effective adsorbents like activated carbon and modified polymers can be expensive. Finding low-cost alternatives or developing efficient synthesis methods is crucial [46].
2. Sorption capacity: the sorption capacity of an adsorbent depends on how well it can remove diuron from water or soil. Some adsorbents may have a limited capacity and require larger amounts of adsorbent material or more replacement [47].
3. Regenerability: Adsorbents must be regenerated or discarded after use. Regeneration includes the removal of absorbed diuron from the adsorbent and the possibility of reusing it. However, regeneration of adsorbents can be challenging, especially if the disposal process requires harsh conditions or additional chemicals. Environmental hazards are significant in the adsorption where we only have phase transfer and no elimination. Developing adsorbents that can be easily regenerated without compromising adsorption efficiency is a key challenge. 4. Selectivity and competition: In real-world scenarios, diuron often co-exists with other pollutants or symbionts, such as other herbicides or organic matter. Disturbance caused by organic substances in the environment should be taken into account. These substances may win in the competition with diuron for adsorption sites. Designing adsorbents with high selectivity for diuron, even in the presence of competing materials, is a challenge that needs to be supervised [48].
4. Selectivity and competition: In this approach, diuron often appears together with other contaminants or symbionts, for example, other herbicides or organic compounds. The interference induced by organic substances in the environment should be taken into

Table 1
Disadvantages of method removal diuron.

Row	Method type	disadvantages
1	Biological treatment	Slow performance - low efficiency - need for nitrogen assessment
2	Filtration	High cost, problems related to filtration of thick water and clogging of filters
3	Adsorption	It is difficult to reuse and recycle. On a larger scale, the synthesis of these adsorbents is difficult.
4	AOPs	Secondary pollution and chemical use

account. These substances may compete with diuron for adsorption sites. The development of adsorbents with high selectivity for diuron, even in the presence of competing substances, is a challenge that must be overcome [49].

5. Long-term stability: The permanency of the absorption capacity of adsorbents is one of the most significant points of adsorption. Long-term effectiveness can play a specific role in the elimination of diuron. Leaching, degradation or sedimentation affect the stability and performance of adsorbents. Therefore, it is required to select and develop absorbents that have high durability [50].
6. Environmental impact: The stability of absorbents also relates to their environmental impact. Some adsorbents may release harmful by-products or lead to disposal problems after application. An assessment of the toxicological effects on the environment and the fate of the sorbents in the environment is necessary to ensure that their use for the disposal of diuron does not lead to additional environmental problems [51].

2.3. Using novel adsorbents

Activated carbon is often applied to eliminate organic contaminants from water, including pesticides, herbicides, pharmaceuticals and industrial contaminants [45]. The high adsorption capacity and porous structure of activated carbon, which is derived from cassava residue biomass, ensures that it adsorbs a broad range of organic contaminants, enhancing water quality and decreasing the risk of contamination. Some limitations and concerns including Variability in Properties‹Limited Availability‹Pre-treatment Requirements‹Regeneration and Disposal‹ Application Specificity and ‹Competing Adsorbents led the researchers to look for new adsorbents that are suitable in terms of stability, adsorption capacity, and cost for diuron removal.

New adsorbents such as Multi-walled carbon nanotubes) MWCNTs (As-prepared, MWCNTs-Oxidized, RHA, BFA and CPAC.

It has been used in the removal of diuron and has shown a significant adsorption capacity. Studies show that MWCNTs Oxidized has the highest adsorption capacity of diuron but in recent years, researchers have tended towards absorbents that are cheap and made from waste we will discuss their features in this review. In the research by Yucan Liu et al. a modified sewage sludge-derived biochar (SDMBC600) was produced for the effective elimination of diuron, using sewage sludge-derived biochar (SDBC600) as raw material and Fe–Zn as modifier. The high specific surface area (204 m^2/g) and pore volume (0.0985 cm^3/g) resulted in a maximum absorption capacity of diuron of 17.7 mg/g and above. Biochar was able to sustain a good adsorption capacity of about 13 mg/g at pH 10–2. The adsorption mechanisms of SDMBC600 for diuron included surface complexation, π-π-bonding, hydrogen bonding and pour filling, which had an efficiency of 96.6 after four regenerations [52]. Fig. 1 illustrates the mechanism of adsorption of diuron in CPAC [53].

2.3.1. BAW-200

This compound called bottom ash is the result of coal combustion in thermal power plants. It has received special attention for 2 reasons. 1- Cheapness 2- Recycling with ethanol.

Its high absorption capacity has led researchers to recommend it as one of the main options for removing a diuron.

The positive performance of bottom ash and its high correlation indicate that waste capacities can be used to improve the quality of wastewater. Another adsorbent applied in the novel ways of eliminating Diuron is bottom ash waste. This by-product of solid waste incineration has been investigated as a potential adsorbent for the elimination of Diuron from aqueous solutions. Here is an overview of the process of diuron elimination by bottom ash waste.

1. Adsorption mechanism: diuron molecules in aqueous solution adhere to the surface of ash particles. The adsorption process involves interactions between diuron and surface functional groups such as hydroxyl (-OH), carboxyl (-COOH) and silanol (-SiOH) groups existing on the ash surface.
2. Surface properties: bottom ash waste usually contains a complex mixture of inorganic components, including metal oxides, carbon and unburnt organic residues. The specific surface area, pore size distribution and surface charge of fly ash can affect the adsorption

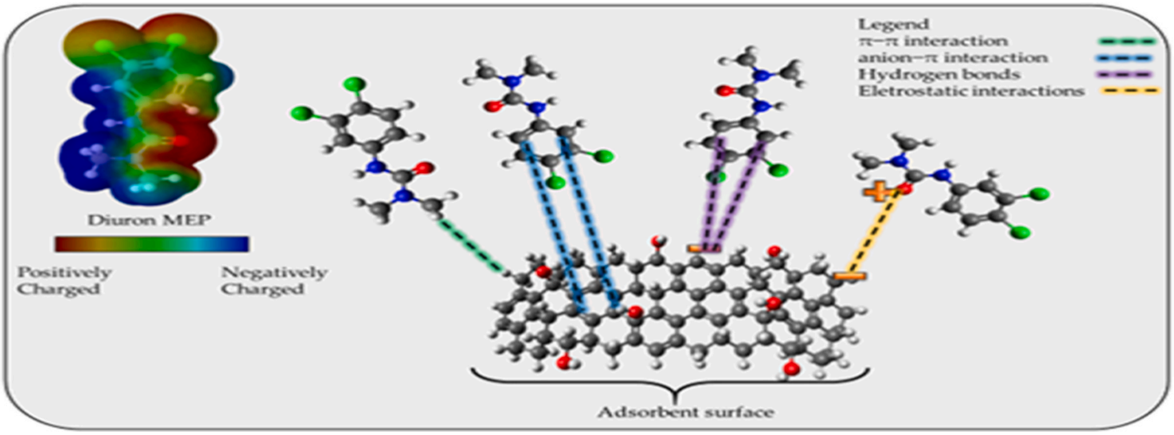

Fig. 1. Diuron adsorption of mechanism into CPAC.

capacity and efficiency of diuron elimination. The occurrence of metal oxides in the ash ca 3. Pathway of pH-dependent adsorption: The pH of the water solvent plays an important function in the adsorption of diuron in slag. Generally, the adsorption capacity increases with decreasing pH due to the increase of the positive charge on the ash surface. At lower pH values, the diuron molecules are positively charged and exert an electrostatic attraction on the negatively charged ash surface. At high pH values, however, diuron is deprotonated and negatively charged, which decreases the adsorption affinity.

4. Competitive adsorption: The occurrence of other symbiotic substances in water solution, such as organics or ions, may compete with diuron for adsorption sites in bottom ash. This competition may affect the overall elimination efficiency of diuron. For example, the existence of organic matter may lead to reduced absorption due to blockage effects or steric hindrance reasons. Understanding the potential interactions and competition between different compounds is essential for optimizing the removal process [54].
5. Regeneration and reusability: bottom ash can potential be regenerated and reused for several adsorption cycles. Regeneration processes, like washing with suitable solvents or pH adjustment, can desorb the adsorbed diuron from the ash surface. Nevertheless, the regeneration efficiency and the impact on the adsorption capacity of the ash need to be carefully assessed to ensure effective and sustainable reuse [54].

It is critical to note that the efficiency of diuron elimination with bottom ash can vary.

2.3.2. SDMBC600

This bio char obtained from sewage sludge was used together with iron and zinc as an activator to remove diuron. The mechanism of adsorption of diuron on this adsorbent is the formation of complexes and the binding of hydrogen and filling the pores with iron activator. This process is environmentally friendly and its positive result is the reduction of secondary pollution of the activated sludge to remove organic pollutants. Fig. 2 is a schematic of the absorption process of diuron with this bio char. The modification of bio chars with iron and zinc is due to the increase in specific surface area and magnetic facilitation, and this effect leads to a threefold improvement in adsorption capacity. A number of widely used modification methods are utilized to upgrade the adsorption characteristics of biochar derived from sewage sludge. These techniques aim to expand the surface area, introduce functional groups or improve the surface reactivity of the biochar [55]. Some frequently applied modification methods are introduced below.

1. Chemical activation: in chemical activation, biochar extracted from sewage sludge is treated with activating agents like strong acids (e.g. phosphoric acid, sulphuric acid) or alkalis (e.g. potassium hydroxide, sodium hydroxide). The activation process increases the porosity and surface area of the biochar by creating more pores and increasing the number of active sites. Chemical activation can considerably improve the adsorption capacity and efficiency of the biochar.

    Physical activation: Physical activation is accomplished by subjecting biochar derived from sewage sludge to physical processes such as steam activation or carbon dioxide activation.

2.4. Comparison of efficiency of adsorbents in removing diuron from water environments

In order to properly analyses the absorption of Diuron by different adsorbents, Table 2 shows the types of adsorbents, absorption capacity, initial concentration of Diuron, pH and adsorbent dose in the studies conducted in recent years. Also, in Fig. 3, the percentage of diuron removal for each adsorbent is mentioned.

2.5. Kinetic study

To describe the adsorption characteristics of diuron on adsorbent materials in all studies. And in each study, isotherm models are specified. Which model (Langmuir, Freundlich, Radeshkevich, etc.) is best described in this review In Table 3, the kinetics of each equation is described, which degree they follow [58,59]. Fig. 4 shows the kinetic study diagram of BAW-200 adsorbent. Kinetic studies are required to understand the adsorption process of a substance on absorbent materials. In the case of diuron, studying its adsorption kinetics can provide valuable information about its behavior and interaction with different adsorbents.

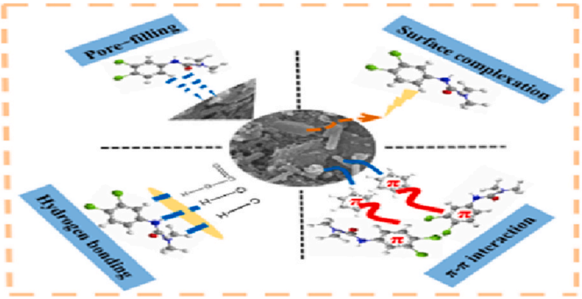

Fig. 2. Schematic of the adsorption process of diuron with this biochar.

Table 2
Different studies of diuron removal through adsorbents.

Row	Adsorbent	Initial Concentration (mg/l)	Adsorbent Dose (g/l)	Adsorption temperature	Optimum pH	Adsorption capacity	Reference
1	RHA	20	3.82	30	6.5	4.13	[56]
2	BFA	20	4.77	30	6.5	6.77	[56]
3	MWCNTs-As-prepared	453	0.15	25	7	28.37	[52]
4	MWCNTs-Oxidized	453	0.15	25	7	29.82	[52]
5	Activated Carbon	13–38	1	40	7	485.11	[53]
6	CPAC	50–200	1	50	7	96–166	[53]
7	BAW-200	40–5	20	20	6.7	349.52	[57]
8	SDMBC600	16	0.075	35	7	17.7	[32]

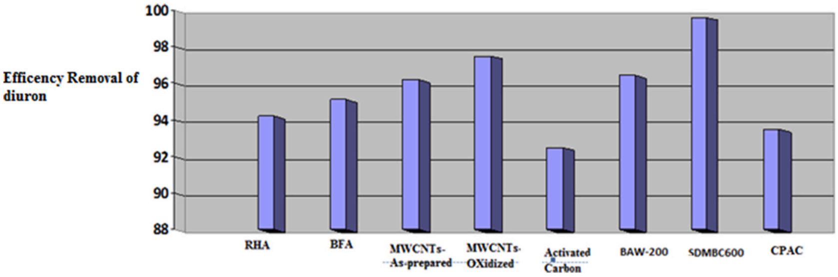

Fig. 3. Efficiency Removal of diuron each of the adsorbents.

Table 3
Kinetic studies of the Langmuir model of diuron removal.

Study	Related model	Degree	reference
Herbicide diuron removal from aqueous solution by bottom ash: Kinetics, isotherm, and thermodynamic adsorption studies	Langmuir	first	[57]
A Stable Fe–Zn Modified Sludge-Derived Bio char for Diuron Removal: Kinetics, Isotherms, Mechanism, and Practical Research	Langmuir	Pseudo-second order	[32]

Determining the speed and mechanism of adsorption are the main goals of kinetic studies, these studies show how quickly Diuron molecules are adsorbed on the surface of the adsorbent and what position they follow. In general, these studies include.

1. Experimental setup: preparation of solutions with different concentrations of diuron and use of different adsorbents to check the absorption capacity [60].
2. Changing the call time:
3. Sample analysis: This is reviewed by high-performance liquid chromatography (HPLC) or spectrophotometry.
4. Kinetic models: The experimental data is fitted with different kinetic models ،and it is determined to what degree it follows [61,62].
5. Kinetic parameters: Kinetic parameters affecting the absorption mechanism are recognized.

3. Other novel methods of removing diuron from water environments

3.1. E-PDS

E-PDS is one of the new non-adsorbent methods for the removal of diuron [63].

In this novel technique, this has demonstrated very high efficiency. The electro activated peroxide disulphate system (*E*-PDS) with graphite felt (GF) as cathode was modified and applied for diuron degradation. GF is a carbon-based material with a large three-dimensional active surface area, good electrical conductivity, low cost, chemical resistance [64] and good electrochemical stability, with a wide voltage range and suitable environment to maintain catalytic performance. It also functions as a support for transition metals [65].

Low energy consumption with changing capacitance has led to iron and copper being considered for their cheapness and low toxicity. Fe–Cu materials like $CuFe_2O_4$ [66], Cu0 and CuO can effectively activate PDS to generate SO_4 radical dots. To improve PDS activation and generate more SO_4 radical points to accelerate diuron decomposition, a Fe–Cu-graphite composite (Fe–Cu/HGF) cathode was prepared by heat treatment and impregnation of the support followed by calcination.

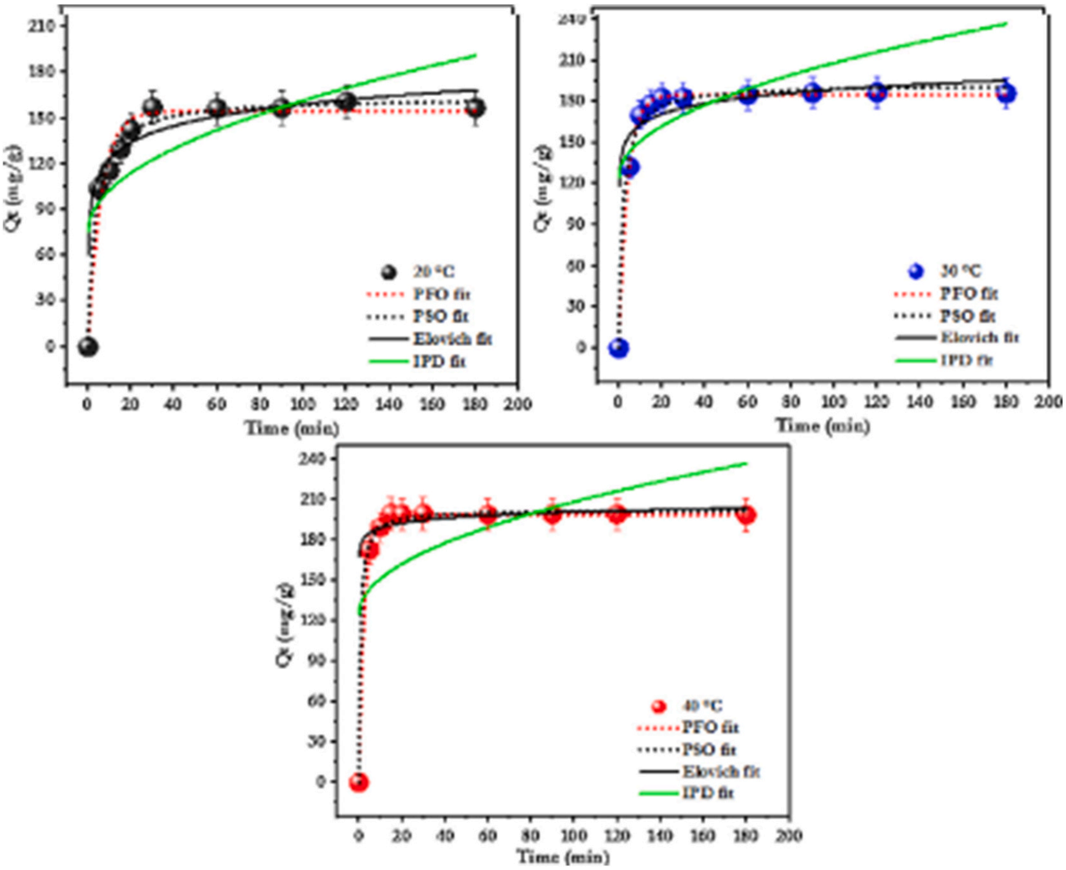

Fig. 4. Diagrams related to BAW-200 kinetics study [57].

In this approach, illustrated in Fig. 5, the iron-copper-graphite electrode carrying the peroxide-sulphate system is activated. The iron-copper-graphite electrode carrying the peroxide-sulphate system is activated, causing a synergy between PDS and the electrochemical processes of the transition metals. This leads to a stronger activation of the persulphate radical and accelerates the

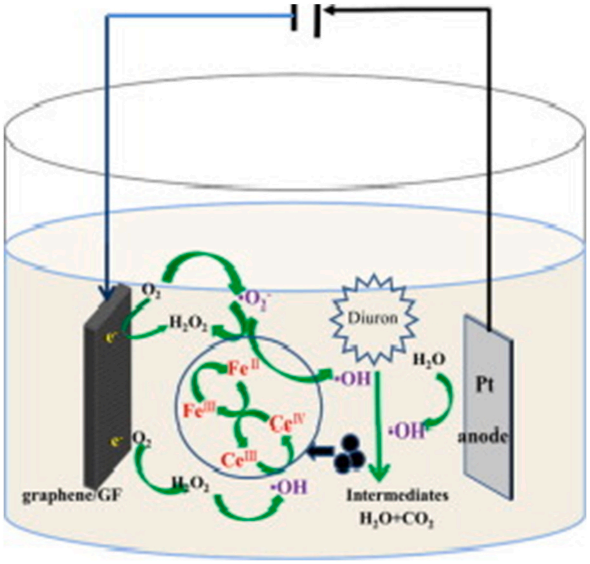

Fig. 5. Schematic of iron-copper-graphite electrode performance in diuron removal from water.

degradation of diuron [67,68]. In summary, the *E*-PDS system with Fe–Cu/HGF as cathode is an excellent treatment method for wastewater containing diuron.

3.2. Hydrodynamic cavitation

This technique is one of the novel technologies for the elimination of diuron from wastewater. One of its desirable characteristics is low price and good performance. Dices a fairly new technique. Accost-effective and energy-efficient technology for wastewater treatment, HDC happens when the liquid flows through a narrowing structure such as a venture orifice, a venturi valve and an activator [69]. In the zone of contraction, the fluid velocity rises at the cost of pressure reduction and cavitation bubbles form. When the pressure is lower than the vapor pressure proportional to the temperature of the liquid, a large amount of cavities form. Downstream construction is subject to recovery pressure It results in the ensuing enlargement of the area cavity collapse, creating extreme conditions and highly reactive free radicals in the water system that it favors many chemical reactions [70]. Degradation of pollutants usually occurs between as physical and chemical effects caused by There have been a number of bubble bursting examples in the literature, associated with the mechanism expressing the chemical changes caused by cavitation [71–73]. With this approach, more than 90 % of the diuron toxin can be removed from the wastewater. There are certain limitations and challenges in the implementation of hydrodynamic cavitation technology. These include.

1. Scale-up challenges: Scaling up hydrodynamic cavitation from laboratory scale to industrial scale systems may be a challenge. The performance and efficiency achieved in small-scale experiments may not translate directly to larger systems. Factors like flow rates, reactor design and maintenance become more complicated in larger systems.
2. Plant design and maintenance: The design and construction of hydrodynamic cavitation plants can be very intricate. The selection of suitable materials that can withstand the harsh conditions induced by cavitation bubbles, such as erosion and corrosion, is critical. Regular maintenance and cleaning of the equipment may also be required to avoid fouling and ensure optimal performance
3. Energy requirements: although hydrodynamic cavitation is considered as energy efficient compared to some traditional wastewater treatment techniques, it still demands an energy input to generate the required pressure differentials and fluid velocities. Energy consumption and associated costs should be closely considered when evaluating the feasibility of this technology.
4. Process optimization: Achieving optimal operating conditions for hydrodynamic cavitation can be challenging. Factors like flow rate, pressure, temperature and residence time need to be optimized to maximize the efficiency of the degradation process while minimizing energy consumption. Extensive research and experimentation may be required to determine the most effective operating parameters for particular wastewater treatment applications.
5. Generation of by-products: During the degradation of pollutants by hydrodynamic cavitation, by-products may be formed. These by-products may have different chemical properties and environmental impacts than the original pollutants. It is essential to carefully analyze and monitor the production of by-products to ensure that they do not introduce additional risks or challenges.
6. Cost considerations: While hydrodynamic cavitation is often touted as a cost-effective technology, its overall cost-effectiveness depends on a number of factors, including equipment costs, maintenance costs, energy requirements and specific application. A comprehensive cost analysis should be performed to assess the economic viability of hydrodynamic cavitation technology [74–76]. Fig. 6 illustrates a view of the hydrodynamic cavitation reactor[77].

4. Conclusion

The ineffectiveness of conventional methods for several reasons, including low efficiency, high cost, production of many by-products, clogging of filters and high consumption of chemicals, as well as the limitations of some common adsorbents such as diversity in properties, limited availability, pre-treatment requirements, regeneration and disposal, the use of specific and competitive adsorbents with short duration made researchers look for new strategies in the removal of diuron. It includes diverse types of novel adsorbents, including SDMBC600 and BAW-200, which are safe and sustainable because of their environmental compatibility and distinguishing features, as well as an overview of the adsorption capacity and performance of each adsorbent in the elimination of this toxin. There are very good adsorbents for pesticides with low production costs that can be utilized effectively to treat wastewater containing diuron. For example, sewage sludge biochar is an excellent adsorbent that has a high capacity to adsorb pesticides as a result of its large surface area. However, the adsorption process is complex and depends on different aspects such as structure, surface chemistry, pH, etc. Therefore, further research is necessary on the durability of the adsorbents, biocompatibility, and absence of by-products and reduction of production costs. Advanced oxidation processes also focus on *E*-PDS and reducing the toxicity of their products in the environment through the application of metals like iron and copper, despite the fact that novel alternative processes that do not require chemicals, such as hydrodynamic cavitation, can also be applied. It seems that in the future researchers will focus on new adsorbents made from dendrimers and agricultural residues. Among advanced oxidation processes, EAOPS, which has been demonstrated to be efficient, will receive more attention. However, reducing the consumption of these herbicides is more people- and environment-friendly, and its realization depends on the optimal utilization of the human-centered agricultural system.

Data availability statement

The Data included in article/supp. Material/referenced in article can allow other scholars to reuse these data on the following Links: https://orcid.org/0000-0002-0414-0532.

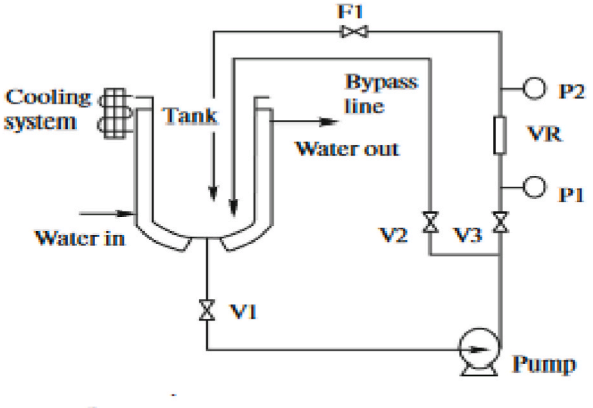

Fig. 6. Schematic Representation of hydrodynamic cavitation reactor.

CRediT authorship contribution statement

Ghorban Asgari: Supervision. **Hossein Abdipour:** Conceptualization, Data curation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. **Amir Mohammad Shadjou:** Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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