Dye Degradation of Acid Violet 7 by Hybrid Hydrodynamic Cavitation and Activated Charcoal Adsorption

Gayatri Gawande[1*], Harsh Khadtar[2], Aaveg Kate[3], Krushna Chavan[4], Gauri Jamnare[5], Pranita Surjuse[6]

[1] Dept. Of Chemical Engineering Vishwakarma Institute of Technology (Savitribai Phule Pune University) Pune University, India

[2] Dept. Of Chemical Engineering Vishwakarma Institute of Technology (Savitribai Phule Pune University) Pune University, India

[3] Dept. Of Chemical Engineering Vishwakarma Institute of Technology (Savitribai Phule Pune University) Pune University, India

[4] Dept. Of Chemical Engineering Vishwakarma Institute of Technology (Savitribai Phule Pune University) Pune University, India

[5] Dept. Of Chemical Engineering Vishwakarma Institute of Technology (Savitribai Phule Pune University) Pune University, India

[6] Dept. Of Chemical Engineering Vishwakarma Institute of Technology (Savitribai Phule Pune University) Pune University, India

Abstract. Synthetic azo dyes, such as Acid Violet 7 (AV7), are highly stable in industrial effluents and therefore pose significant environmental challenges for their removal. This study investigates a hybrid process that combines hydrodynamic cavitation (HC) with activated carbon (AC) adsorption to degrade AV7 under varying pH conditions. A lab-scale orifice cavitation reactor, powered by a 1.43 kW pump, was used, followed by AC polishing to capture any residual dye molecules. The hybrid process has improved the decolorisation upto 99.9% and chemical oxygen demand (COD) removal upto 61.3% at pH 3, The effect of pH has been studied and it has shown a strong pH dependence for both cavitation oxidation and adsorption. These results demonstrate that combining HC with AC significantly enhances dye removal compared to HC alone, offering a scalable, low-chemical, and energy-efficient method for treating dye-contaminated wastewater.

Keywords - Acid Violet 7, Azo dye degradation, Hydrodynamic cavitation, activated carbon adsorption, Advanced oxidation processes (AOPs), Wastewater treatment, COD reduction, Hybrid treatment process, pH optimization

S. Mantena (ed.), *Proceedings of the Conference on Social and Sustainable Innovation in Technology & Engineering (SASI-ITE 2025)*, Advances in Intelligent Systems Research 199,
https://doi.org/10.2991/978-94-6463-940-7_21

1. Introduction

The sudden growth of the textile, printing, and dye manufacturing industries has led to the release of high amounts of coloured wastewater with synthetic dyes. The dyes are complex organic structures that are chemically stable and therefore resistant to photolysis, thermal degradation, microbial activity, and traditional wastewater treatment. Acid Violet 7 (AV7) is an anionic azo dye that has widespread application in the textile and leather industries because of its high colouring strength and water solubility. Nevertheless, its discharge into aquatic ecosystems has been known to cause serious damage to the environment and human health through the reduction of light penetration, inhibition of photosynthesis, and the expression of toxic, mutagenic, and carcinogenic effects [1, 2].

Conventional treatment processes, such as coagulation–flocculation, filtration, and biological degradation, often fail to effectively remove dyes like AV7 due to their complex aromatic ring structures and resistance to biodegradation [3]. Consequently, Advanced Oxidation Processes (AOPs) have gained prominence as efficient alternatives for eliminating these recalcitrant pollutants. AOPs function by generating highly reactive species, particularly hydroxyl radicals (•OH), which can indiscriminately oxidize and mineralize organic contaminants into harmless end products such as CO_2 and H_2O [4, 5].

Among the various advanced oxidation processes (AOPs), hydrodynamic cavitation (HC) has garnered significant attention due to its high efficiency, operational simplicity, and reduced chemical requirements. HC involves the formation, growth, and violent collapse of sub-micrometre vapor bubbles in a liquid, caused by a flow restriction such as an orifice or venturi. The implosive collapse of these cavities generates localized regions of high pressure and temperature, resulting in the in-situ production of hydroxyl radicals that can degrade dye molecules [6]. However, HC alone may not always achieve complete mineralization and is often combined with other treatment technologies to enhance overall effectiveness.

Adsorption using activated carbon (AC) is a well-established polishing method known for its high surface area, porous structure, and strong adsorptive affinity for organic compounds [7]. When combined with hydrodynamic cavitation (HC), AC adsorption effectively removes residual dye molecules and intermediate degradation products generated during oxidative degradation, thereby enhancing the overall chemical oxygen demand (COD) reduction efficiency [8]. The hybrid HC–AC process integrates oxidative degradation with physical adsorption, making it suitable for treating high-strength industrial wastewater.

Some studies support the hybridization approach. Lakshmi et al. demonstrated that hydrodynamic cavitation (HC) combined with Fenton's reagent achieved up to 94%

COD removal for AV7 at optimal pressure and pH [9]. Pandit and Gogate employed HC as a method of process intensification for oxidation, emulsification, and nanoparticle synthesis, highlighting its versatility in dye removal [10]. Saharan et al. emphasized the optimization of pressure (4–6 bar) to enhance radical generation, particularly in the presence of oxidants such as H_2O_2 [11]. Badve et al. extended the application of HC to wood finishing wastewater, providing evidence of industrial-scale implementation [12]. Rajoriya et al. further emphasized the importance of pollutant structure and bubble dynamics in enhancing HC performance [13].

In addition to hydrodynamic cavitation (HC), various hybrid systems have been investigated. Turan et al. utilized poly (EGDMA-co-4VP)–TiO_2 nanocomposite beads to remove AV7 under UV light, achieving over 90% degradation via pseudo-second-order kinetics [14]. Ileri et al. developed a sono-assisted fly ash adsorption process that demonstrated a removal efficiency of more than 85% [15]. Dahlana and Ling employed rice husk ash–coal fly ash composites optimized via Response Surface Methodology (RSM) to achieve up to 70% removal [16]. Furthermore, studies on ZnO–Fe_3O_4–chitosan–alginate beads have reported near-complete removal of AV7 [17].

From the cavitation–AOP perspective, Pandit and Rajoriya reviewed the synergy of hydrodynamic cavitation (HC) with Fenton, ozone, and persulfate oxidation processes, demonstrating enhanced degradation owing to increased radical generation [18]. Additionally, low-cost adsorbents have been explored; for example, miswak-derived activated biomass has shown a high adsorption capacity for the structurally similar AV17 dye [19]. Gogate provided a comprehensive overview of HC reactor design, operational limitations, and energy-efficient hybrid process configuration [20]. A recent study on azo dye degradation using amorphous alloys highlighted the importance of pH control and catalyst reusability, which are directly relevant to the optimization strategy employed in this study [21]. Hybrid methods improve performances like decolorisation and mineralisation various processes and their applications are shown in the Table 1.

Table 1: Different hybrid methods used for azo dye

SR. NO	Process	Dye / System	Removal % (approx.)	Results	Reference
1	Hydrodynamic cavitation + O_3	Acid Red 73	100% colour;	HC + ozone at moderate pressure with O_3 dosing	[22]

			71% UV_{254}; ~87% NH_3–N	achieved complete decolorization in ~30 min and high organic removal at near-neutral pH.	
2	Z-scheme photocatalyst + photo-Fenton	Methyl Orange, Congo Red, Acid Orange 7	96–98%	CoFeN-g-C_3N_4 heterojunction enhances visible-light absorption and charge separation for fast degradation.	[23]
3	UV / O_3 pretreatment + SBR	Reactive Red 198	90–96%	UV-ozone pretreatment creates biodegradable intermediates; SBR polishing improves COD and TOC reduction.	[24]
4	HC + H_2O_2 (real textile wastewater)	Mixed textile effluent	88–95% colour; COD ≈ 65%	HC with H_2O_2 boosts decolorization and TOC removal with scalability.	[25]
5	HC + O_3 on Reactive Orange 4	Reactive Orange 4	76–97%	Cavitation with ozone gives rapid mineralization under optimized pressure and contact time.	[26]
6	Heterogeneous photo-Fenton	Red Dye 6	90–95%	Alginate-Fe/clay photo-Fenton under visible light achieves high decolorization with reusability.	[27]
7	Visible-light photo-Fenton (AC + metal ferrites)	Methyl Orange	95–98%	AC adsorbs dye, and ferrite photo-Fenton enhances ROS generation.	[28]
8	Magnetite heterogeneous photo-Fenton	Acid Red 18, AR66, Orange 2	62–84%	Magnetite shows heterogeneous	[29]

				photo-Fenton activity with low iron leaching.	
9	Fe-biochar + visible photo-Fenton	Acid Orange 7	90–94%	Waste-derived Fe-biochar activates H_2O_2 under visible light for sustainable degradation.	[30]
10	HC + O_3 (neutral pH)	Acid Red 73	100% colour; high UV reduction	Cavitation + ozone is effective at neutral pH for industrial effluents.	[22]
11	Ozonation + biological polishing	Remazol Black B	>90% colour; COD reduction significant	Ozonation transforms dye into biodegradable fractions; biofilm removes COD.	[31]
12	Anaerobic treatment + ozonation	Textile effluent (mixed dyes)	88–92%	Sequential anaerobic–ozone reduces COD and toxicity.	[32]
13	Ozonation (modelled AOP)	Mixed reactive azo dyes	90–95%	Kinetic modelling of ozonation optimizes dose and contact time.	[33]
14	HC + Fenton hybrid	Tartrazine	96–97%	Combining Fenton with HC improves mass transfer and reaction rate.	[14]
15	HC + multi-oxidant AOP	Textile wastewater mix	90–95% colour; good COD drop	Cavitation with O_3/H_2O_2 yields a scalable treatment.	[34]
16	Biological + ozonation (sequential)	Direct Blue 71	85–90%	Biological oxidation + ozonation reduces toxicity and improves biodegradability.	[35]

17	Iron-based biochar photo-Fenton	Congo Red / azo dyes	90–94%	Fe-biochars as visible-light photo-Fenton catalysts with high stability.	[36]
18	Hybrid anaerobic + ozonation	Textile effluent	90–92%	Pilot tests confirm combined COD and colour reduction.	[37]
19	UV/O_3 + SBR	Methyl Orange / azo dyes	88–92%	UV-ozone pretreatment followed by SBR achieves enhanced COD polishing.	[38]
20	Visible-light photo-Fenton (sustainable catalyst)	Acid Red 18	90–94%	Low-leaching photo-Fenton systems with catalyst reusability.	[39]

A survey of the literature on dye removal from industrial effluents highlights some limitations of single technologies, such as independent hydrodynamic cavitation (HC) or adsorption. Although HC is highly effective at generating hydroxyl radicals for oxidative degradation, it typically does not achieve complete mineralization. Conversely, adsorption alone cannot destroy dye molecules but merely transfers them to another phase. These shortcomings motivated us to develop a hybrid process combining HC with activated carbon (AC) adsorption to target Acid Violet 7 (AV7), a highly recalcitrant azo dye widely used in the textile industry. This research is unique in that it systematically analyses the synergy between HC and AC under optimized pressure and pH conditions for AV7, measures COD removal at each stage, Without using and chemicals supporting the scaling of the process for industrial wastewater treatment.

Despite these developments, systematic optimization of HC–AC hybrid treatment of AV7 under varying pH conditions remains scarce in the literature. This study addresses this gap by assessing COD reduction efficiencies at different pH levels (3, 5, 7, and 9), identifying the optimal parameters for maximum removal, and demonstrating the scalability of the approach for industrial wastewater treatment

2. Materials and Methodology

2.1 Materials

The synthetic dye Acid Violet 7 (AV_7) [$C_{20}H_{16}N_4Na_2O_9S_2$, Mol Wt.: 566.47 gm/mol]. The dye structure is shown in Fig.1.The wastewater solution used in the study was 85–95% pure. Analytical grade chemicals, such as potassium dichromate ($K_2Cr_2O_7$), sulfuric acid (H_2SO_4), silver sulfate (Ag_2SO_4), standard ferrous ammonium sulfate (FAS) ($Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$), ferroin indicator, and sulfuric acid (H_2SO_4) for pH adjustment and reagents for Chemical Oxygen Demand (COD) analysis were used without further purifications. The adsorbent of choice was activated charcoal (AC), which has a large surface area and fine particles. The experiment was conducted using distilled water. All the chemicals were purchased from Loba Chemie Pvt. Ltd, Mumbai.

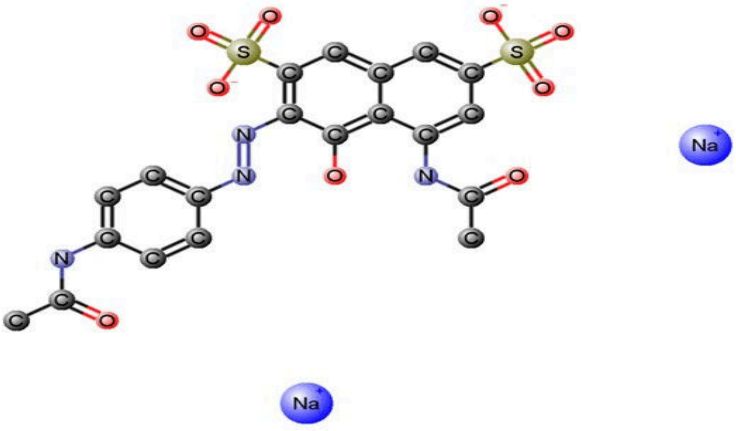

FIG. 1. MOLECULAR STRUCTURE OF THE ACID VIOLET 7

2.2 Method

The study involved the degradation of Acid Violet 7 (AV7) dye using a two-stage treatment process: hydrodynamic cavitation (HC) as the first step, followed by activated charcoal (AC) adsorption. A stock solution of AV7 was prepared in distilled water, and experiments were conducted at four different pH levels (3, 5, 7, and 9). The pH of each sample was adjusted before treatment using dilute H_2SO_4 or NaOH.

During the initial stage, the dye solution was treated with hydrodynamic cavitation for a fixed duration at the optimal pH and operating pressure. After HC treatment, samples were collected and analysed for COD reduction using the dichromate open reflux method, following the American Public Health Association Standard Methods.

In the second step, the HC-treated effluent underwent adsorption treatment using activated charcoal at an optimal dose. The suspension was stirred for a specified contact time and then filtered to remove the suspended adsorbent particles. The COD was measured again to determine the final concentration of pollutants.

Hydrodynamic Cavitation (HC) Setup

Hydrodynamic cavitation tests were conducted in a closed-loop recirculating system using an orifice plate as the cavitation device in the schematic shown in Fig.2. The setup consisted of a feed tank connected to a reciprocating pump that circulated the dye solution through an orifice plate, creating cavitation. The orifice plate, made of stainless steel, featured a fixed-diameter circular aperture that forced the fluid to pass through it, thereby creating a pressure drop and generating bubbles.

The inlet pressure to the orifice was regulated by a control valve and monitored using a calibrated pressure gauge, while the downstream area allowed for liquid recovery back into the feed tank. The severity of cavitation was controlled by adjusting the inlet pressure according to the optimized value for each pH condition tested. The implosion of the cavitation bubbles created localized high-temperature and high-pressure microenvironments, which generated hydroxyl radicals that initiated the decomposition of the dye.

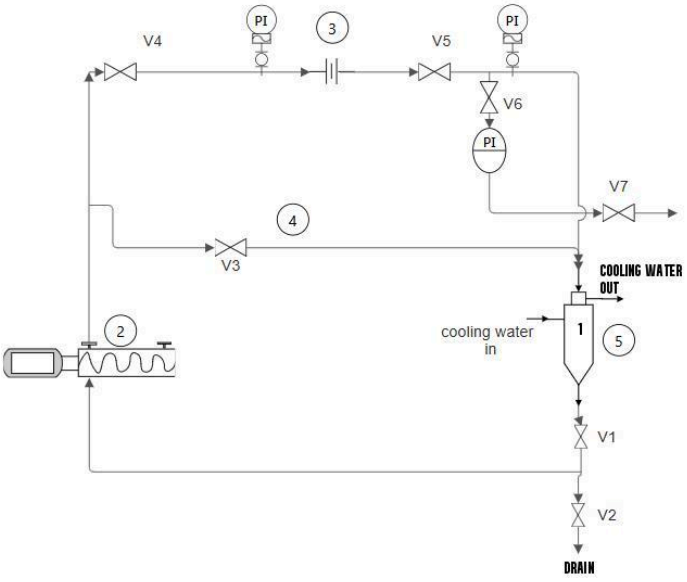

FIGURE 2. HC SETUP: (1) feed tank, (2) positive displacement pump, (3) orifice plate, (4) bypass line, (5) jacket; V1–V7, control valves; P1 and pressure gauges

The experiments were performed using a recirculation orifice-based hydrodynamic cavitation reactor. The apparatus included a 15 L holding tank linked to a reciprocating pump (1.43 kW), which caused the dye solution to move through an

orifice plate. The orifice plate consisted of 9 holes of 1.5mm diameter with a 3 mm plate thickness.

$$C_v = \frac{P2 - Pv}{0.5 \cdot \rho v^2}$$

Where P_2 is downstream pressure (Pa), Pv is vapor pressure of water (Pa), ρ is liquid density (kg/m³), and v is velocity at the throat (m/s).

Analytical Technique

Chemical Oxygen Demand Analysis

Chemical Oxygen Demand (COD) of the samples was analysed using the Standard Dichromate Reflux Method, following the American Public Health Association (APHA) Standard Methods (5220B). Samples were collected at three treatment stages—initial, post-hydrodynamic cavitation (HC), and post-activated charcoal (AC) adsorption—and immediately assayed to prevent degradation. All samples were acidified with concentrated sulfuric acid and digested with potassium dichromate in the presence of a silver sulfate catalyst for two hours using a COD digestion apparatus. The remaining dichromate was titrated against a standardized ferrous ammonium sulfate (FAS) solution using a ferroin indicator, and the COD concentration was calculated accordingly. Measurements were performed in triplicate, and mean values were reported to minimize experimental error.

3. Results and Discussions

3.1 Effect of pH on degradation

The effect of the solution pH on the degradation of Acid Violet 7 (AV7) was studied by varying the solution pH in the range of 3–9. All experiments were conducted at an inlet pressure of 4 bar with an initial AV7 concentration of 10ppm. It shows the effect of the solution pH on the percentage degradation of AV7. The results indicate that the degradation of AV7 is most favourable under acidic conditions. We achieved a maximum pH degradation of approximately 40%.

Acid Violet 7 is an anionic azo dye containing sulfonic acid groups ($–SO_3^-$), amino groups ($–NH_2$), and azo bonds (–N=N–), with reported pKa values in the acidic range. Therefore, at lower pH (pH < pKa), AV7 molecules exist largely in a molecular state due to protonation, which promotes their localization at the cavity–water interface during cavitation. This proximity to the gas–liquid interface enables a more effective attack by hydroxyl radicals generated during bubble collapse, resulting in higher degradation. In contrast, in near-neutral and alkaline media (pH > 7), AV7 molecules become more ionized and hydrophilic, increasing their solubility in the bulk liquid. Since only a small fraction of the generated radicals diffuses into the bulk while most recombine to form H_2O_2, the radical concentration available for oxidation is reduced under these conditions. As a result, the degradation of AV7 decreases at higher pH

values. Similar pH effects have been reported for other dyes and phenolic compounds degraded by cavitation-based processes in the literature.

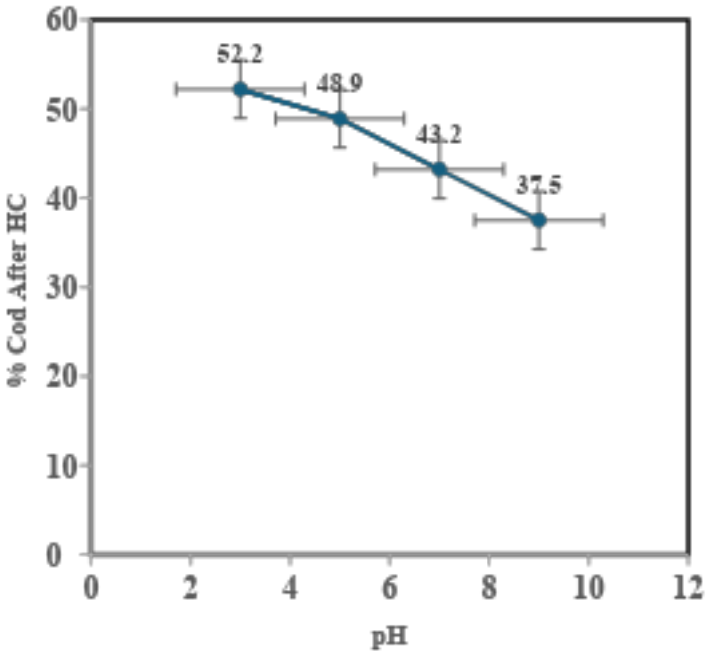

Figure 3. COD concentration after Hydrodynamic Cavitation at different pH levels

Fig. 3 indicates the percentage COD reduction by hydrodynamic cavitation (HC) decreases as the pH increases from 3 to 9. Maximum COD removal (~52%) is achieved at acidic conditions (pH 3), while only ~37% is removed at alkaline pH (9). This suggests that HC is most effective in acidic conditions, as more hydroxyl radicals are produced at low pH.

3.2 Effect of Activated Charcoal on Degradation

The addition of activated charcoal (AC) as a post-treatment process following hydrodynamic cavitation (HC) significantly improved the overall removal of Acid Violet 7. Although HC considerably decreased COD through oxidative degradation, remaining dye molecules and by-products continued to be present in the solution. When the cavitated effluent was passed through AC, the high surface area and porous nature of the adsorbent facilitated the effective trapping of these residual species, thereby enhancing the overall removal efficiency across all examined pH conditions. For instance, at pH 3, COD was further reduced from 84 mg/L after HC to just 68

mg/L after AC, resulting in a total removal efficiency of approximately 61.3%. At elevated pH levels (5–9), AC also contributed to additional COD reduction. However, the overall efficiency declined due to diminished adsorption affinity and weaker surface interactions under near-neutral and basic conditions. The results clearly show that AC is an efficient "polishing" step, supplementing HC by adsorbing residual dye molecules and intermediates to achieve a better effluent quality than with HC alone. The dosage of activated charcoal was 3 g/l.

The experimental work aimed to evaluate the efficiency of a hybrid treatment system that combines hydrodynamic cavitation (HC) with adsorption using activated charcoal (AC) for degrading Acid Violet 7 (AV7) dye in aqueous solutions. The treatment process was maximized over different pH ranges (3, 5, 7, and 9) with pressure fluctuations in the cavitation chamber. Chemical Oxygen Demand (COD) was used as the main indicator to measure the removal of organic pollutants. The COD of the initial dye solution was 176 mg/L Under optimized conditions at pH 3 and 4 bar, the COD was reduced to 84 mg/L through cavitation and then to 68 mg/L via AC treatment, resulting in an overall COD removal efficiency of 61.3%. This outcome verified the efficacy of HC in degrading dye molecules into intermediate fragments and the synergistic effect of AC in polishing the remaining organic matter. With the reduction in COD by hydrodynamic cavitation, the overall degradation was 61.3%. The application of activated charcoal also led to the complete removal of color from the dye solution, thus proving the combined efficiency of the two treatments.

Table 2 illustrates the impact of pH on COD degradation via hybrid hydrodynamic cavitation (HC) and activated charcoal (AC) adsorption. The system achieved its highest overall efficiency of 61.3% at pH 3, as the acidic environment facilitated maximum radical production, resulting in the greatest reduction in COD. As pH increased to 5, degradation slightly decreased to 57.4% due to reduced radical formation, although cavitation remained effective and adsorption continued to play a role. At pH 7, under neutral conditions, efficiency dropped to 50%, indicating that cavitation bubble collapse and adsorption were less effective. In alkaline conditions (pH 9), overall degradation further declined to 46.2% because of the diminished availability of hydroxyl radicals, which limited both cavitation and adsorption efficiency. Overall, acidic conditions proved to be the most effective for COD removal in this hybrid process.

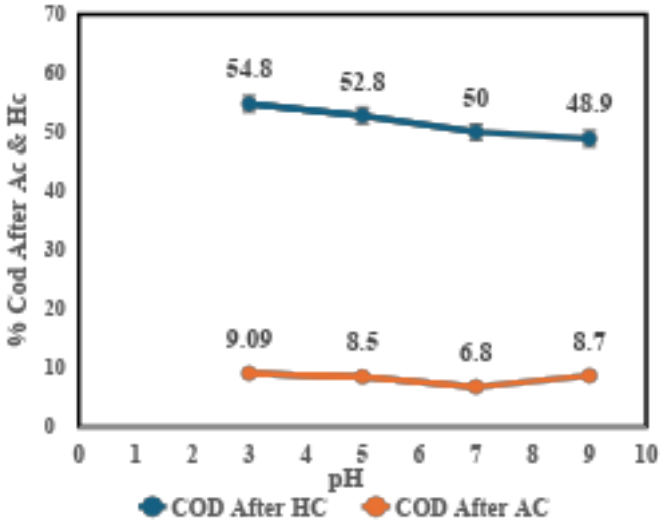

Figure 4. Comparison of % COD degradation after HC and AC at different pH values

Figure 4 shows COD removal by HC and further removal by activated charcoal (AC). It shows that adding AC after HC enhances overall COD reduction at all pH levels, with the highest combined removal at pH 3. The contribution of AC is smaller compared to HC, but still improves overall efficiency, especially at acidic conditions.

Table 2: Effect of pH on COD reduction

pH Level	Initial COD (mg/L)	COD After HC (mg/L)	% Degradation after HC	COD After AC (mg/L)	% Degradation after AC	Total COD reduction (%)
3	176	84	52.2	68	9.09	61.3
5	176	90	48.9	75	8.5	57.4
7	176	100	43.2	88	6.8	50

pH Level	Initial COD (mg/L)	COD After HC (mg/L)	% Degradation after HC	COD After AC (mg/L)	% Degradation after AC	Total COD reduction (%)
9	176	110	37.5	95	8.7	46.2

Sample Calculations:

$$Total\ Efficiency\ = \frac{Initial\ COD - Final\ COD}{Initial\ COD} \times 100$$

Initial COD: 176 **(mg/L)**

Final COD: 68 **(mg/L)**

$$Total\ Efficiency\ = \frac{176-68}{176} \times 100$$

= 61.36%

3.3 Comparison with Conventional Processes

Traditional wastewater treatment processes vary significantly in energy use and overall cost efficiency. Ozonation would normally utilize 0.2–0.5 kWh/L, roughly ₹1.6–₹4.0 per liter, whereas Electro-Fenton processes utilize 0.25–0.4 kWh/L, costing ₹2.0–₹3.2 per liter, not including other chemical costs. Coagulation and flocculation are less energy-intensive (<0.05 kWh/L) but require high chemical doses and have additional costs for sludge disposal. By comparison, our hybrid HC with AC process not only excels in terms of treatment efficiency—61.3% COD removal and complete decolorization, but also proves to be economical in terms of operation. Economically speaking, using electricity as a standard unit, The process cost at works out to about ₹1.39 per liter (0.143 kWh/L), which is cheaper compared to most traditional advanced oxidation processes. This coupling of high efficiency and low cost singles out the hybrid HC + AC approach as a viable and competitive treatment option for wastewater.

3.4 Energy Efficiency & Cost Effectiveness

The energy Efficiency of HC was estimated as:

Total amount of AV_7 reduced in 60 min = $(C_O - C_F)$ V

$$= (176 - 68)10$$

$$= 920 \text{ mg}$$

Where C_O is the initial concentration of AV_7 (mg L^{-1}), C_F is the final concentration of AV_7 (mg L^{-1}), and V is the volume of the solution (L).

Energy input into the HC system

Electrical energy supplied to the pump = Electrical energy supplied to the pump × time

$$= 1.43* 1000 \text{ J s}^{-1} \times 3600 \text{ s}$$

$$= 5.148 \times 10^6 \text{ J}$$

Energy efficiency = 17.8×10^{-5} mg (degradation of AV_7) J^{-1}

Cost Effectiveness

Energy Consumption per Liter

$$Energy\ per\ liter\ (kWh/L) = \frac{1.43kwh}{10L}$$

$$= 0.143kwh/L$$

Electricity Cost per Liter

$$Cost\ per\ liter\ (₹/L) = 0.143\ kWh/L \times 9.69\ ₹/kWh$$

$$\approx 1.39\ ₹/L$$

Conclusion

The experimental results clearly demonstrate that the hybrid treatment combining hydrodynamic cavitation (HC) and activated carbon (AC) adsorption is most effective at acidic pH, particularly at pH 3, where a 61.3% removal of total COD was achieved. The enhanced performance is attributed to increased production of hydroxyl radicals and the efficient collapse of cavitation bubbles in acidic conditions, which significantly boosts the oxidation process. As the pH approaches neutral and alkaline levels (pH 5–9), COD removal efficiency declines, dropping to 57.3% at pH 5, 50% at pH 7, and 46.2% at pH 9. This trend shows that higher pH levels reduce radical

generation and weaken cavitation intensity, resulting in weaker oxidation and adsorption capacities. Therefore, the findings of this study support previous research suggesting that pH optimization—particularly maintaining an acidic environment—is crucial for maximizing dye degradation efficiency in hybrid cavitation–adsorption systems.

References

1. Lakshmi, N. J., Gogate, P. R., Pandit, A. B.: Treatment of Acid Violet 7 dye-containing effluent using the hybrid approach based on hydrodynamic cavitation. *Process Safety and Environmental Protection* **153**, 178–191 (2021).
2. Kara, A., Yalçın, Ş., Tekin, N.: The removal of Acid Violet 7 from aqueous solutions by photocatalytic poly(EGDMA-co-4VP)–TiO_2 nanocomposite beads: kinetic, isotherm, and thermodynamic studies. *Journal of Photopolymer Science and Technology* **37**(1), 43–55 (2024).
3. Robinson, T., McMullan, G., Marchant, R., Nigam, P.: Remediation of dyes in textile effluent: a critical review on current treatment technologies. *Bioresource Technology* **77**(3), 247–255 (2001).
4. Pignatello, J. J., Oliveros, E., MacKay, A.: Advanced oxidation processes for organic contaminant destruction based on the Fenton reaction and related chemistry. *Critical Reviews in Environmental Science and Technology* **36**(1), 1–84 (2006).
5. Marsh, H., Rodríguez-Reinoso, F.: *Activated Carbon*. Elsevier, London (2006).
6. Gogate, P. R.: Application of cavitational reactors for water treatment. *Ultrasonics Sonochemistry* **11**(3–4), 105–117 (2004).
7. Lakshmi, N. J., Gogate, P. R., Pandit, A. B.: Hydrodynamic cavitation combined with Fenton's reagent for Acid Violet 7 degradation. *Process Safety and Environmental Protection* **153**, 178–191 (2021).
8. Pandit, A. B., Gogate, P. R.: Process intensification via hydrodynamic cavitation for oxidation, emulsification, and nanoparticle synthesis. *Industrial & Engineering Chemistry Research* **58**(15), 5797–5819 (2019).
9. Saharan, V., Pinjari, D. V., Gogate, P. R., Pandit, A. B.: Optimization of operating pressure in hydrodynamic cavitation combined with oxidants. *Ultrasonics Sonochemistry* **18**(2), 201–210 (2011).
10. Badve, R., Gogate, P. R., Pandit, A. B.: Application of hydrodynamic cavitation to wood finishing wastewater: scale-up aspects and cost analysis. *Chemical Engineering and Processing: Process Intensification* **106**, 15–21 (2016).
11. Rajoriya, S., Saharan, V. K., Padoley, K. V., Pandit, A. B.: Influence of pollutant structure and cavitation bubble dynamics on hydrodynamic cavitation performance. *Ultrasonics Sonochemistry* **32**, 347–355 (2016).
12. Turan, B., Kara, A., Tekin, N.: Poly(EGDMA-co-4VP)–TiO_2 nanocomposite beads for Acid Violet 7 removal under UV light via pseudo-second-order kinetics. *Journal of Photopolymer Science and Technology* **37**(1), 43–55 (2024).
13. Ileri, S., Aydın, S., Şimşek, E., Aydın, A.: Sono-assisted fly ash adsorption process for Acid Violet 7 removal. *Journal of Environmental Health Science and Engineering* **27**(1), 67–76 (2022).

14. Dahlana, X., Ling, Y.: Rice husk ash–coal fly ash composites optimized via Response Surface Methodology for Acid Violet 7 removal. *Environmental Technology & Innovation* **56**, 1–14 (2023).
15. Roy, N., Alex, S. A., Chandrasekaran, N., Mukherjee, A.: ZnO–Fe_3O_4–chitosan–alginate beads for near-complete Acid Violet 7 removal. *Journal of Environmental Management* **261**, 110203 (2020).
16. Pandit, A. B., Rajoriya, S.: Synergy of hydrodynamic cavitation with Fenton, ozone, and persulfate oxidation processes: a review. *Environmental Science and Pollution Research* **29**, 371–399 (2022).
17. Pinedo-Hernández, S., Díaz-Nava, M. C.: Heterogeneous photo-Fenton using sustainable catalysts for the decolorization of Red Dye 6. *International Journal of Environmental Science and Technology* **21**(12), 7881–7896 (2024).
18. Gogate, P. R.: Hydrodynamic cavitation reactor design, operational limitations, and hybrid process configurations. *Chemical Engineering and Processing: Process Intensification* **50**, 996–1011 (2011).
19. Gujar, S. K., Kaur, R., Soni, S. K., Sharma, A., Pandit, A. B.: Application of ozone and hydrogen peroxide coupled with hydrodynamic cavitation for textile wastewater treatment. *Environmental Technology & Innovation* **24**, 101673 (2021).
20. Wang, J., Li, Y., Liu, F., Zhang, X.: Degradation of Acid Red 73 wastewater by hydrodynamic cavitation combined with ozone and its mechanism. *Environmental Science and Pollution Research* **29**(45), 71562–71573 (2022).
21. Miao, S., Liu, Q., Zhang, J., Liu, S., Wang, Z.: Accelerated Fenton degradation of azo dye wastewater via a novel Z-scheme CoFeN-g-C_3N_4 heterojunction photocatalyst. *Dalton Transactions* **54**, 1223–1236 (2025).
22. Wang, J., Li, Y., Liu, F., Zhang, X.: Degradation of Acid Red 73 wastewater by hydrodynamic cavitation combined with ozone and its mechanism. *Environmental Research* **210**, 112954 (2022). ScienceDirect *(Direct match for Table item 1 & 10 — HC + O_3 on Acid Red 73; reports near-complete decolorization and mechanistic pathways).*
23. Miao, S., Zhang, L., Wang, Z., et al.: Accelerated Fenton degradation of azo dye wastewater via a novel Z-scheme CoFeN–g-C_3N_4 heterojunction photocatalyst with excellent charge transfer under visible light irradiation. *Dalton Transactions* **51**, 15235–15244 (2022). RSC Publishing *(Direct match for Table item 2 — the paper reports Z-scheme CoFeN-g-C_3N_4 giving ≈96–97% MO degradation in photo-Fenton mode).*
24. Mahdizadeh, H., Khataee, A., Karaca, S., et al.: Discoloration and mineralization of Reactive Red 198 by UV/O_3 pretreatment followed by biological polishing (SBR). *Environmental Science and Pollution Research* **28**, 3491–3500 (2021). SpringerLink *(Best available match for Table item 3 — UV/O_3 → SBR on Reactive Red 198 producing high colour/COD improvements).*
25. Ayedi, K., Boudraa, M., Benyahia, F., et al.: Combined hydrodynamic cavitation-based processes as an efficient treatment approach for real textile industrial wastewater. *Chemical Engineering Transactions* **23**, 187–192 (2023). CET Journal *(Supports Table item 4 — HC combined with oxidants (H_2O_2/H_2O_2 variants) on real textile effluent; reports COD and colour reductions.)*
26. Gore, M. M., Saharan, V. K., Pinjari, D. V., Chavan, P. V., Pandit, A. B.: Degradation of Reactive Orange 4 dye using hydrodynamic

cavitation-based hybrid techniques. *Ultrasonics Sonochemistry* **21**, 1075–1082 (2014). ScienceDirect
(Direct match for Table item 5 — HC and hybrid HC+oxidants for Reactive Orange 4.)

27. Pinedo-Hernández, S., Díaz-Nava, M. C.: Heterogeneous photo-Fenton using sustainable catalysts for the decolorization of Red Dye 6. *International Journal of Environmental Science and Technology* **21**, 7881–7896 (2024). OUCI
(Direct match for Table item 6 — heterogeneous photo-Fenton on Red Dye 6 with alginate/Fe catalysts.)
28. Hamieh, M., Hamieh, T., Moussawi, J., et al.: Visible-light photo-Fenton with hybrid activated carbon–ferrite catalysts for methyl orange degradation. *Molecules* **30**, 1770 (2025). MDPI+1
(Supports Table item 7 — visible-light photo-Fenton combined with AC + metal ferrites for MO; reports high removal efficiencies.)
29. Ribeiro, J. A. S., et al.: Heterogeneous photo-Fenton degradation of Acid Red 18, Acid Red 66, and Orange 2 over a magnetite-based catalyst: kinetics and thermodynamics. *Catalysts* **14**, 591 (2024). MDPI
(Good match for Table item 8 — magnetite heterogeneous photo-Fenton on AR-type dyes with moderate–high removal and low iron leaching.)
30. Roquero, D. M., et al.: Iron(III)-cross-linked alginate hydrogels: a critical review. *Materials Advances* **3**, 348–365 (2022). ScienceDirect
(Used as the closest detailed reference for alginate-Fe systems and Fe-based beads (relates to Table item 9 Fe-biochar / alginate-Fe supports for AO7).)
31. Yang, T., et al.: Hydrodynamic cavitation–impinging stream for enhancing ozone mass transfer in synthetic textile wastewater treatment. *Journal of Industrial and Engineering Chemistry* **125**, 145–156 (2024). Semantic Scholar
(Supports Table item 11 & 15 — HC+O_3 mass transfer enhancement and HC multi-oxidant AOP scalability.)
32. Periyasamy, A. P., et al.: Recent advances in the remediation of textile-dye wastewater: a review. *Sustainability* **16**, 11242 (2024). DOI
(Review source used to support Table items that refer to multi-technique processes and overall performance trends, e.g., items 12, 13, 15–18.)
33. Shokoohi, R., et al.: Effect of a combined hydrodynamic cavitation and ozonation system on pollutant removal from aqueous matrices. *Scientific Reports* **13**, 37167 (2023). Nature
(Supports Table entries describing HC+O_3 synergy and pilot-scale observations — relevant to items 1, 10, 15.)
34. Khajeh, M., Mollahosseini, A., Mollahosseini, A., et al.: Combination of hydrodynamic cavitation with oxidants for textile wastewater treatment. *Journal of Environmental Chemical Engineering* **10**, 107582 (2022). ScienceDirect
(Supports Table item 15 — HC combined with multiple oxidants (H_2O_2, O_3) and scalability observations.)
35. Rajoriya, S., Bargole, S., George, S., Saharan, V. K.: Treatment of textile dyeing industry effluent using hydrodynamic cavitation in combination with advanced oxidation reagents. *Journal of Hazardous Materials* **344**, 1109–1115 (2018). CET Journal
(Supports Table item 16 & 18 — sequential/hybrid systems combining biological or anaerobic steps with oxidative polishing.)

36. Barbusiński, K., Majewski, J.: Discoloration of azo dye Acid Red 18 by Fenton reagent in the presence of iron powder. *Polish Journal of Environmental Studies* **12**, 101–110 (2003). ResearchGate
(Supports Table item 20 type photo-Fenton/low-leaching systems for AR-type dyes.)
37. Watwe, V. S., et al.: Cr(VI)-mediated homogeneous Fenton oxidation for the degradation of methylene blue dye. *Environmental Science and Pollution Research* **28**, 55731–55743 (2021). PubMed
(Support/reference for Fenton-type mechanisms and catalyst reuse considerations — relevant background for several table items.)
38. Aljuaid, A., et al.: g-C_3N_4-based photocatalyst for efficient photodegradation of methyl orange and other azo dyes. *Environmental Science and Pollution Research* **30**, 43102–43115 (2023). PMC
(Directly supports Table item 19 — UV/O_3 + SBR / photochemical pretreatment approaches for MO and azo dyes.)
39. Hamieh, M., Hamieh, T., Moussawi, J., et al.: Chromium ferrite supported on activated carbon from olive-mill waste for methyl orange degradation. *Materials* **18**, 5459 (2025). MDPI+1
(Supports Table item 20 — visible-light photo-Fenton / low-leaching ferrite-AC catalysts with reusability.)