Tikrit Journal of Engineering Sciences (2024); 31(1): 33-42
DOI: http://doi.org/10.25130/tjes.31.1.4

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES
Tikrit Journal of Engineering Sciences

Utilizing Hydrodynamic Cavitation with Variable Orifice Patterns for Textile Wastewater Treatment

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Keywords:
Bubble Collapse; COD; Fluid Flow; Pressure; Segmental Plate; Variable Optical Plate.

Highlights:

- *Hydrodynamic cavitation using various orifice plate designs.*
- *The textile wastewater was reduced by cavitation techniques.*
- *Various circular and star-shaped patterns of holes were used to mitigate the issue of COD reduction.*
- *Circle and star type patterns (3 & 5) holes configurations on Orifice plates have magical results.*

ARTICLE INFO

Article history:

Received	07 Nov.	2023
Received in revised form	23 Dec.	2023
Accepted	01 Jan.	2024
Final Proofreading	07 Jan.	2024
Available online	20 Jan.	2024

Citation: Gajbhiye P, Shah VU, Mehta JM, Panchal H, Metre AV. **Utilizing Hydrodynamic Cavitation with Variable Orifice Patterns for Textile Wastewater Treatment**. *Tikrit Journal of Engineering Sciences* 2024; **31**(1): 33-42.
http://doi.org/10.25130/tjes.31.1.4

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Abstract: The presence of hazardous metals, such as nickel and copper, has been identified in the effluents of the textile industries. Due to such hazardous components, this waste water exhibits a significant chemical oxygen demand (COD). Various methods are used to reduce the COD presence in the effluents. This investigation employs hydrodynamic cavitation, to decrease COD levels potentially. This reduction is achieved by implementing different orifice plate designs, including 3-star pattern, 3-circular hole pattern, 5-star pattern, and 5-circular hole pattern, as part of an innovative strategy. According to current investigations, implementing the 5-circular hole layout significantly reduced of COD by 49.14%. In contrast, using the 5-star design yielded a low drop of 34.15% COD. These experimental findings indicated that the most effective orifice plate for removing COD from textile wastewater was a circular design with 5-holes.

الاستفادة من التجويف الهيدروديناميكي مع أنماط الفتحات المتغيرة لمعالجة مياه الصرف الصحي للمنسوجات

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الخلاصة

ظهرت العديد من المعادن خطرة، مثل النيكل والنحاس، في النفايات السائلة الناتجة عن الصناعات النسيجية. ونظرًا لكون هذه المكونات خطرة، فإن مياه الصرف الصحي هذه تظهر طلبًا كبيرًا على الأوكسجين الكيميائي (COD). يتم استخدام طرق مختلفة لتقليل وجود COD في النفايات السائلة. يستخدم هذا البحث التجويف الهيدروديناميكي لتقليل مستويات COD. يتم تحقيق هذا التخفيض من خلال تنفيذ تصميمات مختلفة للوحة الفتحة، بما في ذلك نمط ٣ نجوم، ونمط ثقب ٣ دائري، ونمط ٥ نجوم، ونمط ثقب ٥ دائري، كجزء من استراتيجية مبتكرة. وفقًا للتحقيقات الحالية، أدى تنفيذ تصميم الفتحات الخمس الدائرية إلى تقليل COD بشكل كبير بنسبة ٤٩,١٤٪. في المقابل، أدى استخدام تصميم ٥ نجوم إلى انخفاض منخفض بنسبة ٣٤,١٥٪ من COD. أشارت هذه النتائج التجريبية إلى أن لوحة الفتحة الأكثر فعالية لإزالة COD من مياه الصرف الصحي للنسيج كانت عبارة عن تصميم دائري به ٥ فتحات.

الكلمات الدالة: انهيار الفقاعة، تدفق السائل، ضغط، لوحة مقطعة، لوحة بصرية متغيرة.

1.INTRODUCTION

In the world of textile business, India is one of the leading nations. The manufacturing process produces a significant volume of wastewater each day. There are few potential ingredients which are found in wastewater like varieties of colored dyes, different heavy metals, and other toxic substances which are harmful to the environment and human well-being [1]. Major issue arises when such high potential hazardous wastewater gets releases into the water bodies and thus, creates toxic effects on the surroundings [2]. Hydrodynamic oscillation or cavitation is a highly innovative approach for treatment of such textile wastewater [3]. This simple process involves the liquid's vapor-filling the holes or bubbles which emerges and rupture due to sudden shifts in flow rate or pressure [4]. This phenomenon, resulting in an array of many physical and chemical changes that could be applied to different methods of wastewater treatment, generates significant concentrated thermal energy, elevated pressures, and strong shockwaves [5]. Many a times, hydrodynamic cavitation found effective in deteriorating organic contaminants released during the unit operations employed in the chemical industries. Another way is to convert the Complex molecules of organic matter into less harmful forms by burning, oxidation, and hydrolysis under the present conditions but they are expensive [6]. It was observed that hydrodynamic cavitation is extremely effective for reducing the Chemical oxygen demand (COD) and purifying wastewater that is high in organic debris [7]. This technique also mixes and simplifies the constituents in the effluent, hence increasing the efficiency of diverse chemical processes [8,9]. For instance, it improves the distribution and breakdown of the coagulant or flocculant, allowing the precipitation of the pollutants and enabling their subsequent elimination [10]. This is essential for such industries where chemical procedures are essential for wastewater treatment. Hydrodynamic cavitation also found flexible tool for size reduction and particle disintegration [11]. As discussed previously [4], cavitation bubbles burst forcefully, which break down huge suspended fragments or agglomerates into smaller, easier-to-manage pieces [12]. Particle sizes that are smaller enhance the efficiency of centrifugation and sorting, which is particularly advantageous for companies that are involved in solid-liquid separation procedures [13,14]. Hydrodynamic cavitation also enhances the mass transfer rates and eliminate mass transmission restrictions in above separation processes [15]. Also, the rapid cavitation bubble disintegration creates microjets and shockwaves where the solid and liquid or fluid and gas phases meet. These break up the boundary layers and make it easier for products and reactants to move around [16,17]. Although there are plenty of positive aspects to hydrodynamic cavitation, there are also certain issues and concerns that have to be addressed [18]. While cavitation maintenance on devices could bring up complex issues, producing vortex demands the use of apparatus that can use an enormous quantity of energy. Furthermore, a number of factors, including the wastewater's composition, temperature, and pressure levels, may have an impact on hydrodynamic cavitation's effectiveness [19]. An important tool in fluid dynamics, the orifice plate measures and regulates the flow of different fluids via conduits and tube systems, such as water, air, and other liquids [20,21]. The plates include an aperture or hole in the center that has been precisely and painstakingly created [22]. This opening serves as a means of reducing the pipe's diameter [23]. The underlying concept of their functioning is that the presence of an obstacle, such as an orifice plate, inside a channel of fluid flow results in a proportionate pressure decrease relative to the fluid flow rate [24, 25]. The ability to generate a constant pressure drop across the plate is a notable characteristic of orifice plates, as it enables an exact correlation with the flow rate [26, 27]. different method was reviewed in [28].

Table 1 displays the results and potential outcomes from the study by tabulating a few of the investigated literature allowing for comparing the present research findings with previous literature.

Table 1 Literature Survey Based on Different Experiments of Hydrodynamic Cavitation Device for Wastewater.

Sr. No	Article Title	Important Results from the Study	References
1	Experimental investigation of hydrodynamic cavitation of single and multiple hole orifice for wastewater treatment	# Orifices employ a different kind of circular layout. # To treat textile effluent, filters with varying numbers of holes are used.	Divekar P et.al [21].
2	Recent Developments in Hydrodynamic Cavitation Reactors: Cavitation Mechanism, Reactor Design, and Applications	#Various industrial applications form the basis of the cavitation reactor. #Textile wastewater treatment reactors, stationary and rotating.	Haoxuan Zheng et.al [44].
3	Design and optimization of a cavitating device for Congo red decolorization: Experimental investigation and CFD simulation	# Optimization using CFD and the RSM method was applied to the Venturi orifice. # It was determined by experimenting with various Venturi convergent angles, throat lengths, and divergence angles.	Abbas-Shiroodi Z et.al [24].
4	Intensification of the degradation of Acid RED-18 using hydrodynamic cavitation	# An orifice plate with various circular holes was used to extract RED-18 dye from waste water. # Degradation of waste water based on cavitation number.	Dhanke PB et.al [1].
5	Novel strategies to enhance hydrodynamic cavitation in a circular venturi using RANS numerical simulations	# They employed the circular venturi by adding surface roughness to the wall. # In the diverging portion, single and multiple hurdles were used. # Transforming the planer form of the diverging section into a trumpet shape.	Nilanjan Dutta et.al [46].
6	Present Finding: Reduce COD from textile waste water by introducing orifice plate with different star and circular pattern	# Compared three circular designs with five circular patterns. # Compared the 3-star pattern with the 5-star design. # Reduced COD in textile-dying waste water. # The self-designed reactor reduced COD by adding diverse pattern orifice plates.	Present study

The present research examines the use of precise orifice plates in combination with hydrodynamic cavitation to enhance the textile effluent treatment. This study's primary focus is quantifying and regulating fluid flow via orifice plates with circular apertures. The orifice plates exhibit high precision in their design, including centrally located openings that effectively provide a uniform pressure decrease as fluid flows through them. This study investigates several configurations of orifice plates, specifically focusing on three-hole and three-star patterns, as well as five-hole and five-star patterns.

2.THEORY

2.1.Mechanism of Pollutants Degradation

Pollutants may undergo degradation via various methods, including natural and man-made processes. The precise processes vary based on the nature of the contaminant and the prevailing environmental circumstances. Below are the many prevalent pathways for the breakdown of pollutants: Biodegradation refers to the natural process by which organic substances are broken down into simpler compounds by living organisms, such as bacteria or fungi. Microbial degradation: Numerous contaminants may undergo decomposition by the action of microorganisms, including bacteria, fungus, and algae. These microbes use the contaminants as nourishment, decomposing them into simpler and less detrimental chemicals. Bioremediation is a deliberate procedure in which microorganisms are introduced or promoted to improve the breakdown of contaminants in a polluted environment [42]. Photodegradation refers to the process of breaking down or decomposing a substance through exposure to light. Sunlight can degrade certain contaminants using a chemical reaction known as photolysis. Solar ultraviolet (UV) radiation can trigger chemical processes that result in the breakdown of contaminants. Chemical degradation: Oxidation-reduction interactions: Pollutants have the potential to engage in chemical interactions with oxygen or other compounds, resulting in their decomposition into less toxic substances. For instance, hydrocarbons have the ability to oxidize, producing water and carbon dioxide. The term "hydrolysis" describes the breakdown of some pollutants by a chemical reaction with water. a common occurrence for several types of chemical pollutants. Using plants to eliminate or balance out contaminants in the environment is known as phytoremediation [43]. Plants possess the capacity to absorb, collect, and eliminate contaminants via a process known as detoxification. The term used to describe this process is phytoremediation [47]. Plants can absorb contaminants from the soil or water, which may be retained in their tissues or converted into less dangerous substances [48]. Adsorption: Adsorption refers to the phenomenon when environmental pollutants attach themselves to the surface of solid particles, which may decrease the level of contaminants in the water or soil [49]. Advanced Oxidation Processes (AOPs) use potent oxidizing agents to degrade pollutants, such as the photo-Fenton reaction and ozonation. Illustrative instances include the photo-Fenton reaction and ozonation. Electrochemical degradation breaks down a substance using an electrical current [36].

2.2.Influence of Cavitating Device Geometry

Cavitating devices, which create and use the formation of vapor-filled cavities, are used for a wide range of industrial, medicinal, and scientific purposes. Cavitation is when vapor- or gas-filled cavities (bubbles) develop, expand, and collapse inside a liquid. The geometry of cavitating devices is a critical factor that significantly impacts their performance and efficiency. The following are a few factors that demonstrate the influence of cavitating device geometry: Onset and magnitude of cavitation: The configuration and dimensions of the cavitating apparatus may impact the circumstances in which cavitation is triggered. Certain geometries impact the cavitation occurrence, which can either encourage or hinder it. The properties of the local geometry and factors like the fluid flow's velocity and pressure determine this impact. Bubble dynamics refers to the study of the behavior and movement of bubbles [50]. The size, configuration, and collapse mechanism of cavitation bubbles are all influenced by geometry. As a result, it influences the shock waves, microstreaming, and pressure waves that emerge from the bubble burst. Fluid movement patterns: The cavitating device's shape affects how the surrounding liquid flows [51]. These elements include recirculation zones, vortices, and turbulence, which might impact the device's overall performance and capacity to provide particular effects like cleaning, mixing, or material processing [44].

2.3.The Liquid Medium Properties

The efficacy of wastewater treatment systems, the fibers' nature and colors used, and the particular production methods all contribute to the fluid medium's unique characteristics in textile wastewater. It is well recognized that textile wastewater contains a complex and diverse range of pollutants. Textile effluent may have either an acidic or alkaline pH. Through the use of chemicals, dyes, and finishing agents, the textile processes have an effect on pH. As color is a key component in the classification of textile effluent, eliminating color is an essential goal in wastewater treatment. Because of the organic molecules in textile dyes, chemicals, and sizing agents, the chemical oxygen demand (COD) of textile effluent is usually high. One way to quantify the amount of oxygen microbes use when biologically decomposing organic materials is by looking at their biochemical oxygen demand, or BOD. The high biochemical oxygen demand (BOD) of textile wastewater frequently indicates severe biological oxygen demand in receiving bodies of water [52]. Fibers, dye particles, and other solid byproducts of the production processes are examples of the total suspended solids (TSS) that may be found in textile effluent. Chemicals and salts used in different processes might affect the amount of total dissolved solids (TDS) in effluent from the textile industry. Wastewater containing heavy metals is a byproduct of the textile industry's usage of dyes and finishing chemicals derived from heavy metals. Zinc, lead, copper, and chromium are common heavy metals [45].

2.4.Methods to Evaluate Cavitation Efficiency

An efficiency evaluation is required to know how effectively a cavitating system or device produces and applies cavitation for a given application. Several approaches may be used to assess the cavitation's efficacy, each tailored to a specific application and its intended results. To determine how effective cavitation is, several people use the following techniques: Imaging at high speed: It is possible to record cavitation occurrences as they happen using high-speed cameras. Using this technique, scientists can see cavitation bubbles as they develop, expand, and eventually burst. Image analysis may shed light on cavitation's dynamics and behavior, which can aid in efficiency evaluation. Measuring Pressure: Placing pressure sensors in the liquid medium strategically can help detect cavitation events [53]. Keeping an eye on pressure fluctuations helps to measure how strong cavitation is and how well it produces pressure waves or any other effect one may wish [38]. Evaluation of Sound Levels: Cavitation produces audible sounds during bubble creation and collapse. These signals may be picked up and analyzed using acoustic sensors like hydrophones. Cavitation activity and efficiency may be obtained by measuring the amplitude and frequency of acoustic emissions. Temperature variations: Because bubbles compress and burst during cavitation events, localized heating may result. Cavitation energy dissipation may be better understood by tracking variations in liquid medium temperature. Whether the cavitation application is for cleaning, mixing, sonochemistry, or any other process, the objectives of the application dictate the assessment technique to be used. Typically, to fully evaluate cavitation efficiency, a mix of experimental observations and numerical simulations is used [39].

2.5. Various Parameters Efeect on Hydrodynamic Cavitation Effectiveness

The influence of several pressure fields—linear for hydrodynamic pressure and sinusoidal for acoustic pressure—on the cavity's collapse and ensuing dynamic behavior were investigated in this work. The factors that primarily affect the movement of the cavity or bubble in acoustic cavitation are the initial cavity size, the acoustic field's intensity, and the irradiation frequency [54]. The characteristics that primarily affect the dynamics of the cavity or bubble in hydrodynamic cavitation are the initial cavity size, the ultimate recovery pressure, and the time it takes for the pressure to return to normal. The simulations show that in contrast to acoustic cavitation, which only produces one or two pulses after the bubble or cavity collapses, hydrodynamic cavitation produces several pressure pulses of comparatively smaller amplitude. Research has shown that hydrodynamic cavitation provides enhanced manipulation of operational factors and the resulting intensity of cavitation [37].

3. EXPERIMENTAL PROGRAM

3.1. Apparatus and Procedures

The present experimental study required the following materials: Polyvinyl chloride (PVC) procured from TCI, Tokyo, Orifice plates with circular orifices (8 mm) and star-shaped patterns (8 mm) with all auxiliaries were procured from Aroma Traders, located at GIDC, Ankleshwar, Gujarat, India.

3.2. Measurement and Control of Fluid Flow Using Precise Orifice Plates

The study included the quantification and regulation of fluid flow via the use of circular hole orifice plates. The orifice plates were made with high accuracy, including apertures centrally positioned. The orifice plate's aperture consistently reduced pressure across the plate throughout the fluid's passage [29]. The observed phenomenon of pressure drop was documented, and the collected data was then used to ascertain the flow rate. The aperture's size and the plate's shape were carefully engineered to deliberately create a consistent pressure drop, which could be accurately associated with the rate of flow [30]. The experiment used orifice plates with three holes and three stars, as well as five-hole plates and five-hole stars, as shown in Figs. 1 and 2 respectively.

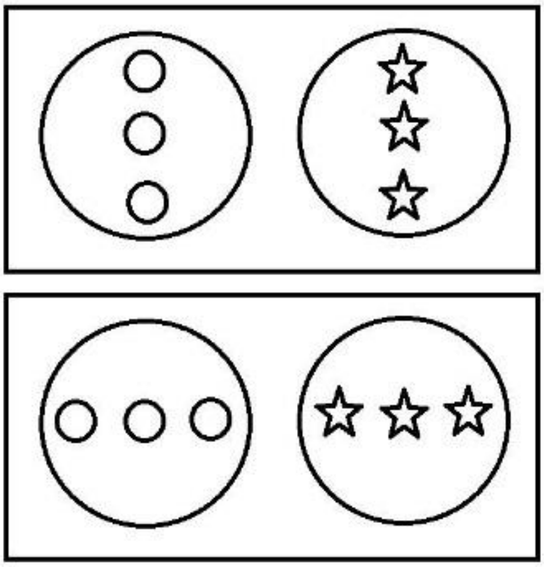

Fig. 1 Orifice Plate with 3-Hole and 3-Star.

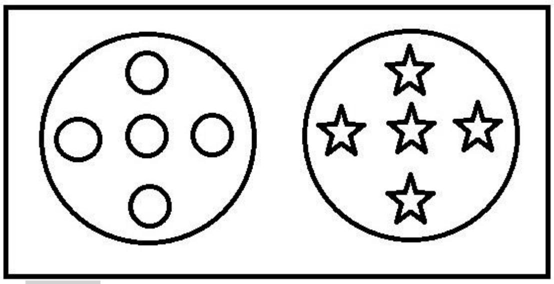

Fig. 2 Orifice Plate with 5-Hole and 5-Star Pattern.

3.3. Salient Features of the Orifice Plate

Fluid flow measurements via pipes and tubes often use orifice plates. Obstructions in the flow channel cause pressure drops proportional to the flow rate [12]. Different orifice plates have different uses and designs. The device had a thin circular plate with a center hole or aperture to decrease the pipe diameter. This process measures air, water, and other fluids. The orifice must be centered and aligned with the pipe axis during installation. The eccentric orifice plate had an off-center hole like the concentric orifice plate. This device is used when the fluid includes particles that might hinder flow. The plate with segmented orifices had an opening cut at 20° to 70° relative to the circle's circumference. The quadrantal fringe orifice plate was similar to the segmental orifice plate but had rounded corners. Sharp edges on standard orifice plates are less accurate and disturb fluid more than this option. Measurements of viscous and suspended liquids are excellent using this approach. Unlike conventional orifice plates, the conical intake plate was intended to limit flow disturbances and pressure recovery losses, reducing downstream turbulence and recirculation. The plate had a wedge-shaped restriction instead of a circular opening. This instrument was used to quantify the gases flow with high velocities and in difficult flow conditions [31]. It allows consistent and reliable flow rate measurements regardless of flow rate. The right orifice plate depends on the fluid being monitored, flow conditions, accuracy, clogging risk, and installation environment. Careful selection and execution are required for accurate flow measurements.

3.4.Impact of Cavitaion Mechanism

Fig. 3 shows the cavitation for removing COD from water. Researchers have shown efficiencies decrease from 30% to over 90% depending on cavitation severity, exposure period, water characteristics, and initial COD level [32, 33]. Cavitation characteristics such as pressure amplitude, frequency, and exposure duration affect COD reduction. Together, these parameters define cavitation optimality [31]. Cavitation research showed that specific settings provide excellent outcomes. Deviation from this range decreased COD reduction, making energy use unproductive [19]. Cavitation's synergistic properties could improve water purifying methods. Previous research [34, 35] shows. cavitation with chemical oxidation techniques like ozone or hydrogen peroxide may work synergistically to reduce COD.

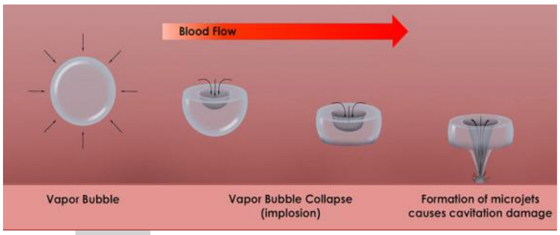

Fig. 3 Cavitation Mechanism [33].

3.5.Experimental Sets

The experiment required a completely integrated PVC orifice plate in the pipe. Thus, the orifice plate had three apertures, five apertures, and three and five asterisks. Apertures and heavenly bodies are usually characterized as 8 mm wide. Fig. 4 shows the hydrodynamic cavitation experiment setup, wherein two side clamps hold a 2.5 mm pipe to a brusher with a single aperture plate. This assembly was linked to the pump's input area, enabling flow rate determination and centrifugal pump operation. The assembly's intake and discharge are near the pump's suction and tank respectively. An orifice plate cavitates wastewater from the input to the outflow. The hollow formed as water discharged from the orifice moved. A round shape and star-like pattern appeared at the start. This hydrodynamic flow of water reduced COD in the generating cavity. Water passing through the hole while crossing it generated the hollow. As water traveled through a cavity-forming mechanism, COD concentration fell.

Fig. 4 Experimental Set Up and Cavitation Process.

Fig. 5 Simple Orifice Design with Attached Pipe.

As shown in Fig. 5, the homemade gadget was assembled from pipe, a flange, and a busher. The orifice plate was mounted between the pipe, the flange, and the busher, to modify the orifices into different patterns like a circle or a star.

4.RESULTS AND DISCUSSION

4.1. Comparative Analysis of COD and Color Reduction in Different Orifice Plate Configurations

Properly managing wastewater, particularly in industrial sectors such as textiles, is a significant environmental issue of utmost importance. The prioritization of sustainable practices involves assuring pollutant-free wastewater discharge to the environment. A novel method for attaining this objective involves using hydrodynamic cavitation in combination with specifically engineered orifice plates. The findings shown in Table 2 and Fig. 6 provide insights into the efficacy of this approach in mitigating COD and color in wastewater generated by the textile industry. As shown in Table 2, the effect of various orifice plate configurations on decreasing COD and eliminating color was observed with different design concepts. Hydrodynamic cavitation, a phenomenon characterized by the generation and subsequent implosion of vapor-filled voids within a liquid medium, has shown a significant pathway in wastewater treatment. Research team here put enormous work for reducing the high COD level to permissible limits as per the norms of government of India. The innovative approach was processing the textile waste water through variety of holes provided in the orifice plates. The outcomes observed was reduction in % COD by 6.8 and % color reduction by 25.04. This was only possible by novel approach of providing three different circle type holes on the orifice plate sizing diameter of 8mm. This observation implies that using circular apertures can substantially enhance the quality of wastewater generated by textile production. Nevertheless, the true revelation occurred when contrasting these findings with those acquired using orifice plates with three star-shaped apertures of 8mm each. The star-shaped orifice plate exhibited superior performance to its circular counterpart, resulting in a decrease in COD by 9.19% and removal of color by 24.97%. highlighting the effectiveness of star-shaped apertures in orifice plates for reducing COD. It is noteworthy that while there was a notable divergence in the COD reduction between the circular and star-shaped designs, there was an incomparable discrepancy in color removal. Both designs demonstrated comparable efficacy in moving color from the wastewater, suggesting that selecting an orifice plate design may have a greater impact on reducing COD than on color removal. The researchers examined the effects of a five-hole orifice plate including 8mm holes, on the levels of COD and color, as shown in Table 3 and Fig. 7. The findings exhibited notable outcomes, including a decrease in COD by 49.14% and an elimination of color by 34.15%. which implies that increasing the number of apertures in the orifice plate considerably improves its efficacy in the treatment of textile wastewater. Nevertheless, the orifice plate, which had a star-shaped design and five holes measuring 8mm each, showed the potential to reduce effectiveness. This reduction in COD was 34.42%, whereas the decrease in color was measured at 13.44%. Although it could not accomplish the same COD reduction as the five-hole circular design, it could consistently sustain color removal [40]. Hong et al. discovered that the elliptical orifice's cavitation shape had a characteristic horseshoe form at the nozzle exit plane and that the cavitation length on the main axis plane was higher than on the minor axis plane by comparing the cavitation dispersion in circular and elliptical orifices [41].

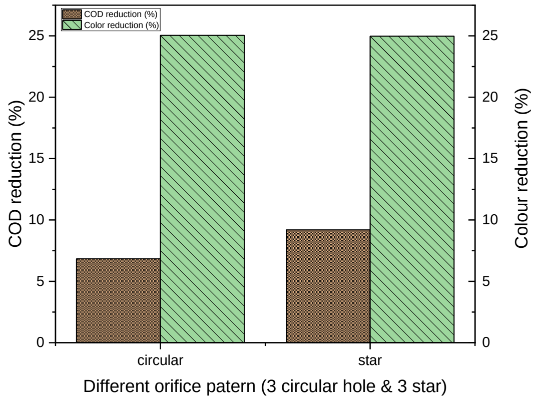

Fig. 6 Experiment Run of 3-Hole and 3-Star.

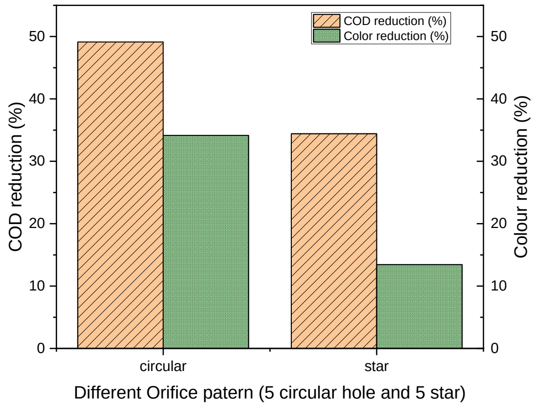

Fig. 7 Experiment Run of 5 Hole and 5 Stars.

Table 2 Experiment Run of 3 Circular Holes and 3-Star Hole Orifice Plates.

Sr. No	Hole type	Hole size (mm)	Hole Number	Flow rate (m^3/h)	Time (sec)	Initial COD	Final COD	% COD reduction	% Color removal
1	Circular	8	3	6.6	15	2100	1956.26	6.84	25.04
2	Star					2100	1907	9.19	24.97

Table 3 Experiment Run of 5 Circular Hole and 5-Star Pattern Orifice Plates.

Sr. No	Hole type	Hole size (mm)	Hole Number	Flow rate (m^3/h)	Time (sec)	Initial COD	Final COD	% COD reduction	%Color removal
1	Circular	8	5	6.6	15	2100	1068	49.14	34.15
2	Star					2100	1377	34.42	13.44

5.CONCLUSIONS

Combining hydrodynamic cavitation with purposefully engineered orifice plates exhibited considerable potential for effectively remedying textile wastewater. The results from the studies demonstrated notable advancements in reducing COD and color in effluent generated by the textile sector. The research emphasizes the significance of orifice plate design in determining the efficacy of this therapeutic approach. Circular perforations, particularly when using three holes with a diameter of 8mm, have shown significant promise, decreasing COD by 6.8% and color by 25.04%. Nevertheless, it is worth noting that the star-shaped orifice plate exhibited superior performance. compared to the circular design with identical specifications. Specifically, it achieved a decrease in COD of 9.19% and removal of color by 24.97%. The observation above highlights the enhanced effectiveness of star-shaped apertures in orifice plates in reducing chemical oxygen demand (COD). Moreover, using a five-hole orifice plate, regardless of its circular or star-shaped form, significantly improved the efficiency of the wastewater treatment procedure. Implementing a circular design with five apertures significantly decreased COD levels by 49.14% and color intensity by 34.15%. These findings suggest that increasing the number of apertures beneficially reduced COD and color in the system. Although the COD reduction obtained by the star-shaped design with five holes was significantly the lowest at 34.42%, it exhibited constant color removal at 13.44%.

6.FUTURE SCOPE

1- The optimization of orifice plate designs can be further investigated with different patterns, sizes, and combinations to determine the most efficient combination for reducing COD and removing color.
2- Enlarging the scope of the experiments to replicate real-world industrial situations would provide significant information into the pragmatic feasibility of these methodologies on a broader magnitude.
3- Future research should prioritize evaluating the environmental consequences associated with implementing wastewater treatment systems. This assessment should include an analysis of energy consumption and the possible development of by-products.
4- Using a cost-effectiveness study to evaluate the financial implications of various orifice plate designs and configurations may assist companies in making well-informed choices about implementation.

ACKNOWLEDGEMENTS

The authors are grateful for the contingency towards this research by the Chemical Engineering Department, School of Engineering and Physical Science, Lovely Professional University, Punjab.

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