NOVATEUR PUBLICATIONS
JournalNX- A Multidisciplinary Peer Reviewed Journal
ISSN No: 2581 - 4230
VOLUME 10, ISSUE 9, September - 2024

MUNICIPAL WASTEWATER TREATMENT BY HYDRODYNAMIC CAVITATION

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Abstract
Wastewater is any water that has been adversely affected in quality by anthropogenic influence and comprises liquid waste discharged by domestic residences, commercial properties, industry, and/or agriculture and can encompass a wide range of potential contaminants and concentrations. Release of such polluted waste water in the surrounding environment which is most toxic to the aquatic life and human health. Cavitation is one of the phenomena which is applied for treatment of waste water for reduction of different hazardous parameters that are released in environment. This contaminates the natural water, so its effect should be mitigated, for this there are several processes utilize viz. Sono electrochemical Catalytic Oxidation, Acoustic cavitation, Hydrodynamic Cavitation Advanced Oxidation processes. Wastewater from sources including domestic, municipal, or industrial liquid waste products disposed of, usually via a pipe or sewer system. Untreated sewage may contain water; nutrients (nitrogen and phosphorus); solids (including organic matter); pathogens (including bacteria, viruses and protozoa) and textile raw materials, etc increases the water polluting parameter. By usage of techniques namely Sonofenton, ultrasound cavitation, Sonolysis, AOP, Ozonation and Ultrasonic dying the toxicity of chemicals is reduced. To meet the need of better and safer environment cavitation is the good process to degrade the several pollutants that causes pollution. All analysis gives the result that fulfils the required outcome with an effective result.

Keywords: Cavitation 1, Advanced oxidation process (AOP) 2, Hydrodynamic Cavitation (HC) 3, Total Dissolve Solids (TDS) 4 Chemical oxygen demand (COD) 5, Biological oxygen demand (BOD) 6 Municipal Waste Water (MWW) 7

1. INTRODUCTION

Availability of water is becoming an increasing concern in the globalised world, both in developed and in developing countries. A sustainable use of water sources could result in the search of additional water sources or even in recycling wastewater treatment plant effluents . The goal of biological wastewater treatment is a stepwise oxidation of organic pollutants aiming to achieve complete mineralisation. Yet, numerous wastewater constituents are persistent to biodegradation or they are only subjected to minor structural changes instead of complete transformation into carbon dioxide and water. In short. With the development of industry and the rapid growth of population, the current water treatment technologies face many challenges. Hydrodynamic cavitation as a green and efficient means of water treatment has attracted much attention. During the hydrodynamic cavitation, enormous energy could be released into the surrounding liquid which causes thermal effects (local hotspots), mechanical effects (pressures) and chemical effects (hydroxyl radicals). These conditions can degrade bacteria and organic substance in wateswater. By adopting such an advanced technologies, waste water pollution is reduced at source itself. Thus the water natural resources may be protected from contamination. Also treated waste water is used for gardening, vehical washing etc. Therefore need of municipal waste water management is essential in Latur district.

1.1 Parameters to be analyzed

The municipal waste water coming out from domestic residences, commercial properties, industry, and/or agriculture has gone tremendous change in their physical and chemical characteristics. Depending upon the operation of the industry, physical and chemical characteristics of the effluent will vary and which ultimately decides the impact of that effluent to the environment when it is released in to the stream if not treated properly. The physical characteristics such as colour, odour, temperature, turbidity does not plays a vital role in polluting the stream but the chemical characteristics which includes total dissolve solids, pH value, chemical oxygen demand, biochemical oxygen demand plays a vital role in polluting the stream and extent and the type of treatment required for its safe disposal.

1.2 Selection of Parameters

As stated above the chemical properties of the effluent are main concern for its safe disposal, hence for analyses we select the chemical properties such as pH, Total Dissolved Solids, Chemical Oxygen Demand (C.O.D) and Bio-chemical Oxygen Demand (B.O.D) to be analysed by using cavitation method for the treatment of waste water coming out from municipal.

2. LITERATURE REVIEW

2.1 Cavitation

Cavitation is defined as the technique of formation, growth and continuous collapse of microbubbles which is occurring in short intervals of time. It is the procedure that produces conditions which is extremely suitable for the degradation or destruction of pollutants. The degradation of pollutants is need current condition that has to be solved efficiently to meet the need of better and safer environment .

2.2 Types of cavitation

Cavitation is used in wastewater treatment, in general includes the generation, growth, and rapid collapse of bubbles or cavities. The collapse of cavities induces effects such as high shear forces, extreme temperatures, shock waves, turbulence, and extreme pressure in the fluid.
Among the four types (particle, optic, ultrasonic, hydrodynamic), the last two types of cavitation are widely in use.

1. Ultrasonic cavitation - Ultrasonic cavitation is produced due to pressure fluctuations induced by ultrasonic waves traveling through the fluid. Ultrasonic cavitation is sometimes called acoustic cavitation.

2. Hydrodynamic cavitation - In hydrodynamic cavitation, the fluid in motion undergoes a rapid change in the velocity profile, which leads to localized pressure drops.

2.3 Hydrodynamic Cavitation

Hydrodynamic cavitation is the cavitation phenomenon that involves the development of vapor cavities inside a liquid medium. Hydrodynamic cavitation involves three mechanisms as Nucleation, Bubble growth & Bubble implosion

Hydrodynamic cavitation can be described as the breakdown of the fluid medium under low pressure. When a fluid flow passes through irregular geometries or narrow orifices, the velocity of the fluid rises. The rise in velocity decreases the static pressure. Whenever the pressure becomes less than the local saturated vapor pressure, a large number of cavities are released (nucleation). Upon the pressure drop, the generated cavities expand and break down (growth and implosion). When the cavities collapse, they release sharp shock waves of energy into the surrounding fluids. The shock waves are capable of bringing the microscopic mixing effect, scale-free heating, and controllable rotor/liquid friction.

2.4 Hydrodynamic Cavitators

The mechanical rotation of the fluid using a specialized rotor (with holes) at a specific velocity can produce hydrodynamic cavitation. The specialized rotors used for generating hydrodynamic cavitation are called hydrodynamic cavitators.

In hydrodynamic cavitators, the rotation of the rotor produces hydrodynamic cavitation away from the metal surface within the holes. The hydrodynamic cavitation produced by hydrodynamic cavitators is completely controllable within the system, which prevents surface damage. The implosion of the bubbles discharge shockwaves that help blend and inhibit scaling. The hydrodynamic cavitators provide uniform distribution of temperature throughout the liquid without any heat transfer surfaces.

3. MATERIALS AND METHODS

As the cavitation method has been selected for treating the waste water collected from drainage it is needed to setup a small scale hydrodynamic cavitation reactor for which a cavitation producing devices has be selected. For this project work we select the orifice meter as the cavitation producing devices for the small scale hydrodynamic cavitation reactor.

3.1 Characteristics of the liquid

Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Experiments of HC were performed on the sample collected from municipal wastewater of Latur.

Experiments on hydrodynamic cavitation were performed on the activated
sludge collected from the municipal WWTP of Trento, Italy. The activated sludge

used in this study had an initial suspended solids concentration o

3.2 Experimental set-up

The plant designed to produce hydrodynamic cavitation, the Cavitation Loop, consists of a tank (containing the contaminated liquid), a discharge pipe with a pump and a convergent/divergent section orifice plate known as cavitation chamber after which the liquid flows back to the tank. Cavitation is forced through high-speed loop circulation. The liquid first accelerates in the convergent section, as a result pressure decreases and therefore bubbles generate and grow. In a second stage the liquid enters a diverging section and decelerates, giving raise to pressure recovery and bubbles implosion. The liquid is circulated and cavitated during a period of 60 minutes. The experiments were carried out in a medium scale cavitation loop.

Fig. No.3.1 illustrates the experimental setup for HC, which includes a 3 Lit holding tank, a pump, manual control ball valves, pressure gauges and cavitating device. The pump of capacity 1HP (Kirloskar) is used. The stainless steel material was used for fabrication of the setup. Hollow square pipe supporting frame (1.5 cm x 1.5 cm) is used as a support for mainline, bypass line and tank. The pump inlet is connected with the bottom of the holding tank. An outlet of the pump is divided into two lines, a bypass line and a mainline. The control valve on the bypass line controls water flow through the mainline. The mainline is equipped with a cavitating device, and pressure gauges P_1 and P_2 measures pressure and downstream recovered pressure, respectively. There is a submersion of the mainline and bypass line below the solution level within the holding tank to prevent air entrapment, which may lead to a variation in the results

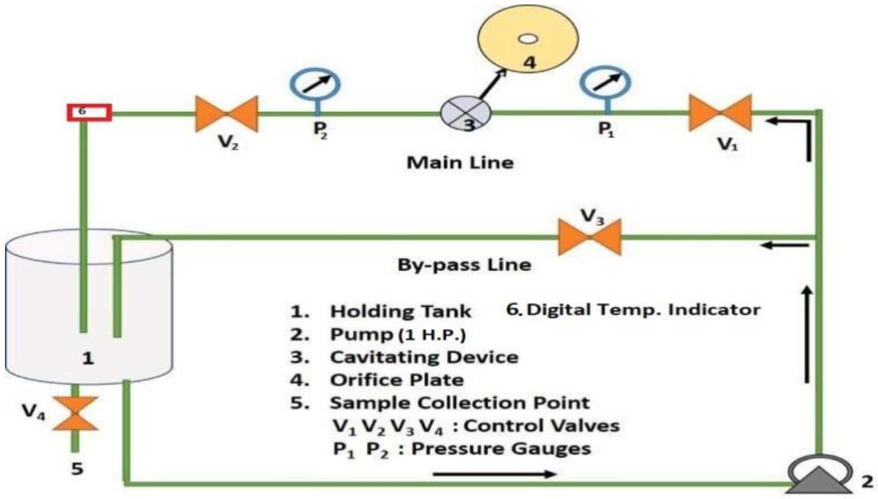

Fig 1. Schematic diagram of a hydrodynamic cavitation system

As shown in Fig. 1, the cavitating device used in our setup is an orifice plate made from SS 316. Single hole 0.5 mm thick orifice plate with 1 mm diameter hole in the centre is used as cavitating device and is fitted on the mainline. The setup was cleaned by circulating water for 5 min before each experiment. The orifice was detached and cleaned properly with detergent during the cleaning process. Before conducting any experiment, all water was removed to prevent sample contamination and dilution.
Experiment was conducted by using double holes and triple holes(each of 1mm dia) orifice plate.

4. RESULTS AND DISCUSSION

After collecting the samples of waste water and giving treatment for every 5 minutes interval following are results obtained for all the parameters values.

Table No. 1 : Duration Vs Temperature

Run No 1 (Room Temp. 29.6°C)		Run No 2 (Room Temp. 27.5.°C)	
Double Hole Orifice (1mmdia)		Triple Hole Orifice (1mm dia)	
Time Interval (Min.)	Wastewater Temp. (oC)	Time Interval (Min.)	Wastewater Temp. (°C)
0	27.9	0	25.8
5	35.8	5	32.3
10	41.9	10	37.7
15	46.5	15	42.4
20	50.6	20	46.4
25	**54.1 - S_1**	25	49.8
30	57.9	30	**52.8 -S_1**
35	61.1	35	56.0
40	63.2	40	58.5
45	65.0	45	60.5
50	**66.20 - S_2**	50	**62.1- S_2**

Note - S_1 – Sample 1 & S_2 – Sample 2

4.1 Data Analysis and Interpretation

Analyze the differences between pre-treatment and post-treatment samples for each parameter. Assess the percentage reduction or increase in contaminants and other metrics.

Table No. 2 : Result Analysis of MWW sample Parameters for Run No. 1

Sr. No	Parameters	Raw Sample	Treated Sample S_1	Treated Sample S_2
1	pH	6.97	7.31	7.40
2	Turbidity, NTU	270	80.9	104
3	TDS, mg/l	865	666	757
4	D.O. ,mg/l	0	0	0
5	C.O.D .mg/l	165	47.6	54
6	B.OD.mg/l	62.7	16.3	19
7	NO3mg/l	26.9	10.4	22.6
8	PO4mg/l	6.4	2.90	3.24
9	Oxygen absorbed, mg/l	57.2	5.76	8.90

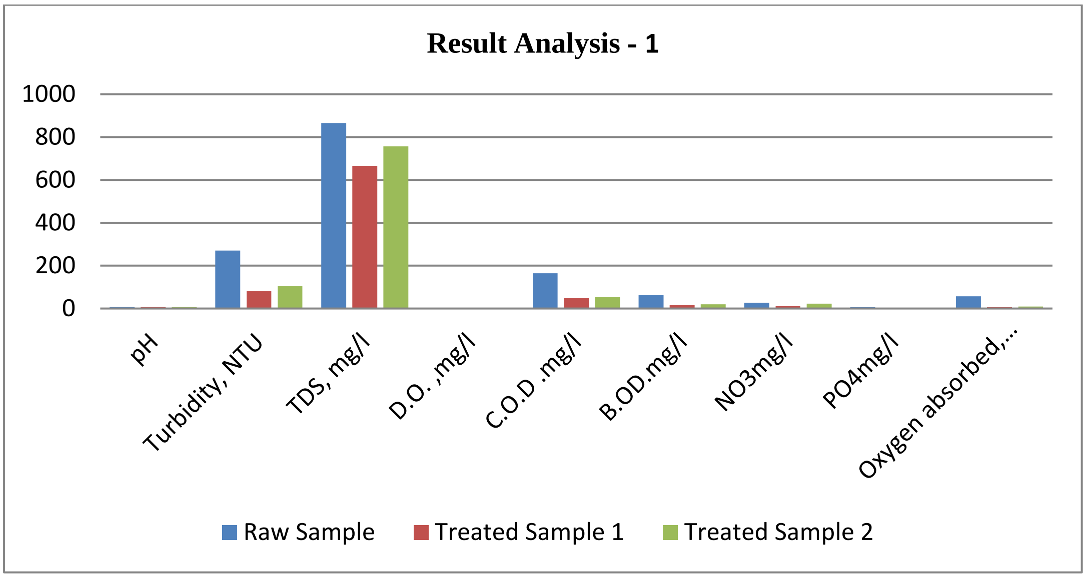

Fig 2. Graphical representation of variation in parameters for Run No. 1

Table No. 3 : Result Analysis of MWW sample Parameters for Run NO. 2

Sr. No	Parameters	Raw Sample	Treated Sample 1 S_1	Treated Sample 2 S_2
1	pH	7.29	7.44	7.70
2	Turbidity, NTU	105.7	96.5	120.5
3	TDS, mg/l	1258	1237	901
4	D.O. ,mg/l	0	0	0
5	C.O.D .mg/l	197	70.6	116
6	B.OD.mg/l	72.4	24.7	40.1
7	NO3mg/l	20.1	10.8	18.85
8	PO4mg/l	26.2	3.85	5.76
9	Oxygen absorbed, mg/l	82.4	10.4	16

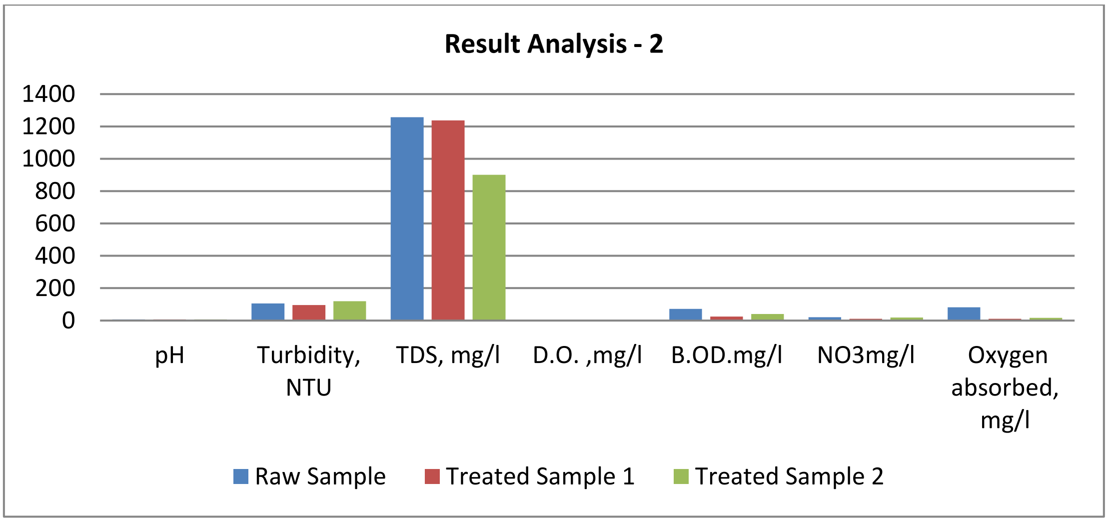

Fig3. Graphical representation of variation in parameters for Run No. 2

From the table No. 2 and 3 it is observed that there is slight increment in the pH of raw sample after treatment and large reduction in all other parameters of raw sample.

During the early period (25 min to 30 min) temperature increases rapidly and after that the rate of rapid increase decreases. i.e. temperature steadly increases. Desired results are observed for sample S_1

4.2 Statistical Analysis

Apply statistical methods to determine the significance of observed changes. This procedure will help in effectively sampling and analyzing wastewater treated by hydrodynamic cavitation, providing insights into the efficiency of the treatment process.

Table No. 4 : Percentage in reduction in contaminants

Sr. No	Parameters	Run No. 1 (Sample1)	Run No. 2 (Sample1)
1	2	3	4
1	Turbidity, NTU	70.04	8.70
2	TDS, mg/l	23.01	1.67
3	C.O.D .mg/l	71.15	64.16
4	B.OD.mg/l	74.00	65.88
5	NO3mg/l	61.34	46.27
6	PO4mg/l	54.69	85.31
7	Oxygen absorbed,mg/l	89.93	87.38

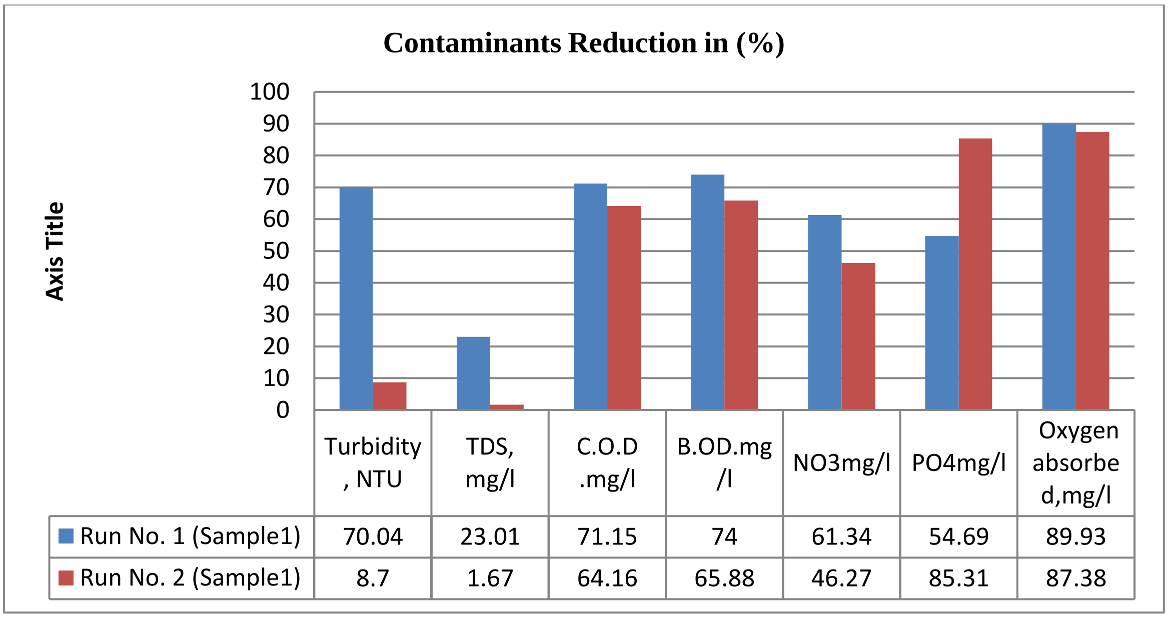

Fig4. Percentage reduction in contaminants

It is clear that (Table No. 4) for smaller opening area of orifice, there is a large reduction in contaminant percentage because of more cavitation.

5. ENEGRY CALCULATIONS

Energy consumption and treatment costs for Hydrodynamic Cavitation (HC) as an Advanced Oxidation Process (AOP) are critical factors when evaluating its feasibility for wastewater treatment.

5.1 Hydrodynamic Cavitation

The holding tank of the HC setup has a working volume of 3 L. For HC, a plunger pump was utilised (power 0.746 kW); An orifice (double hole) with a diameter of 1 mm serves as a cavitation device.

I. Total volume of liquid = Dead volume + System volume

In this case, the total volume of liquid is 4 L.

Considering the reactor size, pipe sizing, and liquid accumulated in the pump chamber, the system volume is estimated to be 1 L.

II. Hence, dead volume = total volume – system volume

dead volume = 4–1 = 3 L

III. Total amount of energy dissipated in HC:

Energy dissipated (ED) = dP × Q × T

Q = Volumetric flow rate of the sample through orifice

Q = 198 LPH

T = Total circulation time through the orifice = 60 min

DP = Pressure drop across the orifice nozzle = 4 bar = 3.9×105 Pa.

Flow rate at 4 kg/cm^2 ,

(Q) = 198 LPH

(Q) = $198\times10^{-3}/3600\ m^3/sec = 5.5\times10^{-5}\ m^3/sec$

Energy dissipated into the system,

(ED) = $(3.9\times10^5)\ (5.5\times10^{-5})\ (60\times60)$ = 77220 J = 77.22 kJ

IV. Cavitation number,

$$C_V = \frac{P_2 - P_V}{\frac{1}{2}\rho v^2}$$

Where, Inlet fluid pressure = 4 kg/cm^2 = 3.9 ×105 Pa

Downstream recovered pressure (P_2) = 101325 Pa

Absolute pressure = Gauge pressure + Atmospheric pressure

Gauge pressure (P_1) = 4 kg/cm^2 = 3.9 ×105 Pa.

Atmospheric pressure = 1 atm = 101325 Pa.

Thus, absolute inlet pressure

P_{ab} = 3.9×105 Pa + 101325 Pa = 491325 Pa.

Vapour pressure (P_v) of water at 30 °C = 4242.14 Pa.

Volumetric flow rate (Q) = 94.8 LPH = 2.63×10−5m^3/s

Diameter (d) of orifice = 1 mm.

Flow Area (a) = 2 x л/4 x d^2= 2 x л/4 x1^2

(a) $= 1.57 \times 10^{-6}$ m^2

Velocity at the throat of the orifice,

(V) = (Q/a) = 35.03 m/s

Therefore, Cavitation number ,

$C_V = (101325–4242.14)/[0.5\times1050 \times (35.03)^2]$

$C_V = 0.15$

5.2 Treatment Cost

Treatment costs include the cost of electrical energy used for pump operation.

Pressure drop across the orifice, Dp = 4 bar = 3.9×105 Pa

Efficiency of Pump, h = 0.78

Volumetric flow rate (Q) = $198\times10^{-3}/3600$ m^3/sec = 5.5×10^{-5} m^3/sec

Electrical power required for pump ,

P = (Dp x Q)/h= $(3.9\times10^5 \times5.5\times10^{-5})/0.78$ = 27.5 Watt = 0.0275kw

Treatment Time = 60 min (1 h).

Treatment Volume = 4 L.

Energy Consumption,

E = (Electrical power supplied ∗ Treatment time)/Treatment volume

E = $(0.0275 \times1)/(4x\ 10^{-3})$ =6.875 kWh/m^3

In Maharashtra State, the average cost of electricity for the commercial connection is 6.30 Rs./kWh

Electricity cost of treatment = 6.875× 6.30 = 43.31 Rs./ m^3

6. CONCLUSION

The use of hydrodynamic cavitation in environmental engineering technologies allows processes to be greatly effective during water and effluent treatment. A technology which utilises the cavitating liquid environment can be considered as a nonwaste technology and environmentally friendly due to the possibility of degradation of low biodegradable, hazardous and carcinogenic organic compounds, which are resistant to conventional disposal methods.

Hydrodynamic cavitation is a versatile and effective technique for wastewater treatment, offering benefits in pollutant degradation, disinfection, and process enhancement. It can diminish recently necessary use of expensive chemical reagents for advanced treatment process. These chemicals create additional problems when deposited into environment. Finally, as nowadays a lot of attention is put upon micro pollutants such as endocrine disrupting compounds, it is expected that developed process of wastewater treatment with aid of cavitation will considerably reduce their presence in purified water. While there are challenges in terms of operational control and material durability, ongoing research and development continue to advance the applicability of this promising technology.

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