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Energy Efficiency in Bacterial Treatment of Wastewater by Hydrodynamic Cavitation

Elmer Benites-Alfaro[a,c*], Arantza Olivera López[b], Mery Rengifo Pereyra[a], Carlos Castañeda Olivera[a]

[a]Universidad César Vallejo, AV. Alfredo Mwendiola 6232, Los Olivos, C.P. Lima 15314, Perú
[b]Benemérita Universidad Autónoma de Puebla, 4 Sur 104 Centro Histórico C.P. 72000, México
ebenitesa@ucv.edu.pe

Helping energy consumers to make the best decision in the use of energy is essential to save it, as well as to take advantage of it conveniently. There are many wastewaters treatment processes that generate negative impacts on the environment and it is necessary to require new forms of treatment, seeking to mitigate said impacts; Thus, in recent years, a physical phenomenon considered harmful has been taken into account, but now it is sought to take advantage of it positively to decontaminate and improve the quality of surface and waste water, we refer to hydrodynamic cavitation. Hydrodynamic cavitation in water treatment is a technology that is on the rise due to its environmental advantages as it does not use chemical products as is done with some traditional methods. Given the question about the energy consumption necessary to generate hydrodynamic cavitation in the bacterial disinfection of wastewater, the research aimed to determine the energy efficiency for each unit of energy in the reduction of the "microbiological load" parameter presented by domestic wastewater, during the treatment time. The result, after 80 minutes, using cavitation equipment that operated with a 3.37 kWh pump, the energy efficiency was found to be the elimination of 2,344 MPN of bacteria for each joule consumed; In addition, the value of the microbiological parameter was within the maximum permissible limits established by the Peruvian environmental authority. Therefore, hydrodynamic cavitation turns out to be a possibility for the treatment of bacteria in domestic effluents, it does not generate polluting residues, it has low energy consumption and probably low economic cost; In parallel, other physicochemical parameters also improved

1. Introduction

Water scarcity worldwide, as well as the increase of contamination in water resources are an issue of great importance, these have been causing many social conflicts and damage to health. (Távares and Álamo, C., 2020). Currently, a trend has been generated in research and projects that seek new ways of performing domestic and industrial wastewater treatment, with the aim of increasing its efficiency, effectiveness, viability and sustainability (Arcila and Peralta, 2015); however, few research works consider energy consumption, losses and energy efficiency of the processes as a relevant variable to take into account in the treatment results. There are different methods of wastewater treatment, and three classes can be distinguished: physical methods, chemical methods and biological methods, and there are also certain combinations of these, such as electrochemical and physical-chemical methods and others (Torres G., 2014).
Hydrodynamic cavitation is a physical process that requires energy to propel the fluid at high pressure into the cavitating system to achieve the formation and intense implosion of vapor bubbles that occurs when liquids are subjected to a pressure drop due to an increase in velocity when passing through a constriction. Hydrodynamic cavitation is indicated is a non-conventional technology for the treatment of different products, by-products and agro-industrial waste, in hydrodynamic technology the flow velocity of the liquid stream is considerably increased at the expense of pressure and it was established that it is much more efficient, from the energy and operational point of view, in contrast to the use of traditional techniques for the processing and transformation of raw materials, products and waste from the agricultural sector (Gutiérrez-Mosquera et al., 2019)

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This technology has been tested for the treatment of slaughterhouse water with the purpose of reducing the organic and nitrogen load (Cadenas and Santos, 2020), to decontaminate the microbial load (Gashchin and Viten'ko, 2008). It has also been used to eliminate cyanobacteria and microalgae in water with good results (Matevž D., et al., 2016). Karamah E. and Sunarko I., (2013) carried out a study on the inactivation of Escherichia coli using a hydrodynamic cavitation reactor using a Venturi tube and an orifice plate, decreasing from the initial concentration of 104 CFU/mL to zero CFU/mL after 30 and 20 minutes respectively for said cavitating devices; Another study demonstrated the efficient bacterial disinfection of contaminated water from the Santa Clara River, Ecuador, concluding that when the discharge pressure increases, the degree of disinfection efficiency also increases (La Fuente E., and López H, 2018). It has been established that hydrodynamic cavitation offers an immediate and realistic offer in wastewater treatment (Gogate P.R. and Pandit A. B., 2005).
In recent years, this technology has been taken up again to solve problems in the treatment of wastewater contaminated with harmful elements, despite the fact that it probably still cannot compete economically with the chemical method of chlorination (very common), if it has been shown to be effective in cavitation that by itself (without the addition of chemical agents), compensates for the energy expenditure that this demands; Likewise, in some cases it was shown that the use of the venturi is better in terms of energy efficiency, because it requires a less permanent pressure drop (Carpenter et al., 2016). In this context, the objective of the research was to determine the energy efficiency of hydrodynamic cavitation to minimize the bacterial load in domestic wastewater.

2. Methodology

2.1 Cavitation phenomenon

It is a phenomenon that occurs when there is a change of state from liquid to vapor due to the sudden variation in pressure, produced by effects of deposition of hydrodynamic, acoustic or optical energy. The bubbles or cavities of vapor that form within the liquid grow until the pressure and velocity of the fluid are restored within the passage through which they pass, after which they implode and release energy in the form of shock waves (García, J.A. y Calvo Esteban, 2013, p. 184), release large amounts of energy at a certain pressure and temperature (up to 1,000 bar and 10,000°k) in a small region and in multiple places at the same time, see figure 1. Hydrodynamic cavitation has a destructive erosive effect on metal walls; its beneficial use is very varied, among it to destroy microorganisms in contaminated liquids (Domínguez, 2018).

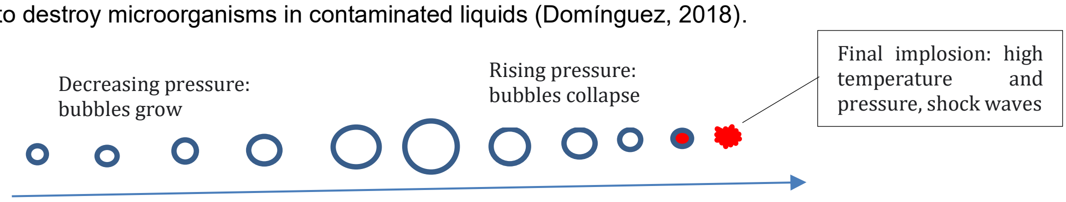

Figure 1. Growth and collapse of a bubble by hydrodynamic cavitation (García and Calvo, 2013)

2.2 Research design

In order to identify the energy consumption of the cavitation process, domestic wastewater treatment was performed in a hydrodynamic cavitation equipment at pilot level.
The process carried out can be seen in Figure 2.

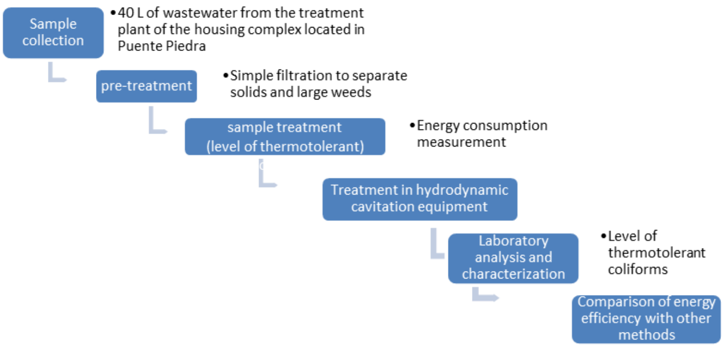

Figure 2: Phases of the research process

2.3 Bacterium removal

The mechanism of bacterial removal is presented by the combined processes of mechanical (physical), chemical and heat effects. The mechanical effect is given by cell rupture in the presence of eddies, vortices and reentrant flows that cause pressure differences in the cell walls (Save S., Pandit A. and Jshi B., 1997) and the chemical one is due to the presence of hydroxyl radical (OH) and physical disruption of cell membranes taking into account the high reactive and toxic power of OH for microorganisms that attacks the DNA chain (Medina I. and Valencia L., 2008). All this also occurs with the generation of heat and high pressure as a consequence of hydrodynamic cavitation (Mezule L, et al., 2009). Energy efficiency.

2.4 Energy efficiency

The energy efficiency calculation was calculated following the method used by Lafuente and Lopez (2018). This procedure takes into account only the consumption of electrical energy. As follows:

- Treatment time (s)
- Volume used (mL)
- Power consumption (W)
- Initial CFU/mL
- CFU eliminated in the treatment time
- CFU removed/W of electrical consumption (CFU/mL)/W
- CFU removed/J power consumption (CFU/J).

2.5 Hydrodynamic cavitation equipment

The hydrodynamic cavitation equipment used was designed and manufactured by Promec Ingenieros as part of the Innovate Project of the Peruvian Ministry of Production. This equipment used a pump with the following characteristics in terms of the energy used in its operation:

TYPE	P 9SL-450/6T
Q (L/MIN)	60-280
H(m)	95.5-66.6
Hmin	33.3
H max	103.1
P2(HP)	4.5-(KW) 3.37
p1 (kW)	4.56
MEI >=	0.4
IP	55
V 3	220/380
T max liquid	110 °C
A	13.8-8
Hz	60

Other operating parameters of the cavitator system were: Inlet pressure 8.2 bar. With an initial temperature of 34.5 °C which increased to 55.2, 59.9 and 62.1 °C at 80, 120 and 160 minutes of treatment respectively. The pH of the sample ranged from 7.71 to 8.56.

3. 3. Results and discussions

3.1 Time, treatment volume and power consumption

Table 1 shows that the total time of treatment of domestic wastewater was 160 minutes, for a volume of 52,000 millilitres, the power of the motor was 3,370 W, appreciating that until the end of the time used, 32,352,000 W were consumed of energy.

Table 1 Energy consumption in the cavitation treatment process

Time of treatment		Volume used (mL)	Engine power (W)	consume electric (W)
(min)	(s)			
0	0	52,000	3370	0
80	4,800	52,000	3370	16 176,000
120	7,200	52,000	3370	24 264,000
160	9,600	52,000	3370	3 252,000

3.2 Characterization of domestic wastewater before treatment.

The wastewater from a housing complex presented the physicochemical and microbiological parameters shown in Table 2. The level of microbiological load is emphasized, since it was based on this parameter that the energy efficiency was evaluated

Table 2: Parameters of untreated wastewater

Parameter	Units	Value
Oils and Fats	mg/L	16.40
Total Organic Carbon	mg COT/L	98.94
Fecal Coliforms (Thermotolerant) (MPN)	MPN/100mL	3 500 000 000.0
Biochemical Oxygen Demand	mg BOD_5/L	180.00
Chemical Oxygen Demand	(mg O_2/L)	395.80
Ammonia Nitrogen	(mg N-NH_3/L)	53514.00
Dissolved Oxygen	mg DO/L	0.48
Total Suspended Solids	mg/L	39.00

3.3 Microbiological load removal from domestic wastewater up to 160 minutes of treatment by hydrodynamic cavitation

Table 3 shows the decrease of thermotolerant coliforms present in the domestic wastewater throughout the hydrodynamic cavitation process. It can be seen that as the treatment process goes on, the coliforms decrease progressively so that after 80 minutes of treatment, 99.99 % reduction of thermotolerant coliforms has been reached and at 160 minutes the level of their presence is minimal (49 MPN). This is due to the presence of hoxydryl radicals, the implosion of the cavities (bubbles) and the high temperature in the hydrodynamic cavitation process (Mezule L, et al., 2009)

Table 3: Reduction of fecal coliforms in water during hydrodynamic cavitation treatment

Time (min)	Fecal coliform (thermotolerant) (MPN/100mL)	Reduction (%)
0	3500000000	0
80	17000	99.9995143
120	70	99.999998
160	49	99.9999986

As can be seen in Figure 3, the percentage decrease of fecal coliforms reached almost 100 % (99.99 %) after 80 minutes of treatment, so this method is very efficient for recovering wastewater from this pollutant, and no further treatment time is necessary

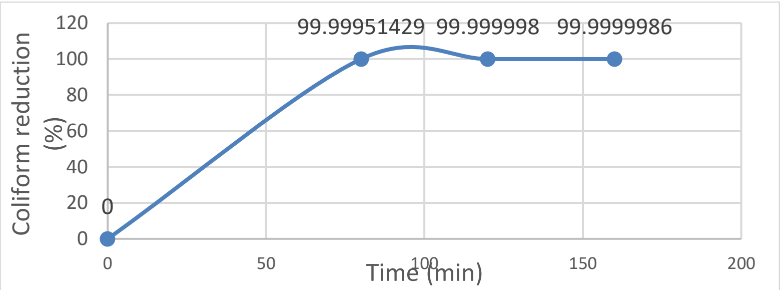

Figure 3: Fecal coliform reduction process (thermotolerant)

3.4 Energy efficiency in the reduction of fecal coliforms (thermotolerant)

Table 4 shows the energy efficiency measured as the amount of fecal (thermotolerant) coliforms that are removed by the hydrodynamic cavitation process per unit of energy in Joules. It can be seen that the best efficiency is after 80 minutes of treatment, eliminating 2,344 NMP of coliforms for each Joule consumed. It is highlighted that the method used in the calculation of energy efficiency is based solely on the consumption of electrical energy for a specific case of fecal coliform disinfection.

Table 4: Energy efficiency in the reduction of fecal coliforms

Time of treatment (min)	MPN/100mL (initial)	MPN/100mL in treatment times	MPN /mL in wastewater removed in the process	MPN /mL removed per Watt of electrical consumption	MPN removed per Joule of electricity consumption
0	3500000000	3500000000	0		
80	3500000000	17000	3499983000	216.37	2344.00
120	3500000000	70	3499999930	144.25	1041.78
160	3500000000	49	3499999951	108.18	586.00

The operating pressure on the liquid in the cavitation process must be taken into account, according to the research carried out by Lafuente E. and López H. (2018), they used 65 liters of water for a time of 65 minutes and decreased 115.77 CFU per each joule of energy, equivalent to 72.8 % of the microbial load when working at 2 bar pressure and 99.5 % when working at 3 bar pressure. In the present investigation, an energy efficiency of 2,344 MPN per joule was obtained in 80 minutes, with a working pressure of 8.2 bar at the inlet of the cavitator (Venturi), with a decrease of 99.99 % (close to 100 %); Therefore, it can be established that it is an efficient method of eliminating thermotolerant coliforms and that the time to achieve an efficient result depends on the type of wastewater, also on the cavitator system to be used, among other parameters; therefore, it is required to establish specific conditions for each case, due to the presence of other contaminants such as benzene and dyes (Bokhari A., Klemes J., Asif S., 2021; Orizano S., Benites E., 2020)

4. Conclusions

It was determined that the hydrodynamic cavitation process is efficient in the removal of fecal coliforms (thermotolerant) from wastewater. In the investigation, for 52 liters of domestic wastewater, 2,344 MPN of fecal coliforms were eliminated for each joule of energy consumed after 80 minutes of treatment, which meant a reduction of 99.9999% of thermotolerant coliforms. On the other hand, it is highlighted that the physical method did not generate dangerous or toxic by-products like the traditional ones (chlorination) for human health.
Although it can be said that there is an energy efficiency to reduce a load of fecal coliforms in wastewater, more research is required to standardize optimal models for the use of cavitation, also taking into account the economic value when it comes to being scaled to an industrial level.

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