Laboratory-scale hydrodynamic cavitation assessment for the disinfection of filtered water in the municipality of Florencia- Caquetá

Evaluación de la cavitación hidrodinámica a escala de laboratorio para la desinfección de agua filtrada en el municipio de Florencia- Caquetá

Avaliação da cavitação hidrodinâmica em escala laboratorial para desinfecção de água filtrada no município de Florencia-Caquetá

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Abstract

Introduction: This article is the product of the research "Laboratory-scale hydrodynamic cavitation assessment for the disinfection of filtered water in the municipality of Florencia- Caquetá", carried out at the University of the Amazon - Macagual Research Headquarters between 2018 and 2019.

Problem: Due to the cost of chemical inputs for disinfection and the lack of trained personnel for the operation of purification systems, it is necessary to search for alternatives that require fewer chemical products and ease of operation to ensure the microbiological quality of the water supplied to the population.

Objective: To evaluate, at a laboratory scale, the efficiency of a hydrodynamic cavitation reactor in terms of reducing the concentration of fecal coliforms for water disinfection in the municipality.

Methodology: In order to explore the results of the proposed alternative and its statistical analysis, a type 32 factorial experimental design is used, in which the variables or factors were the initial pH of the filtered water and the diameter of the venturi throat.

Results: They indicate that for a smaller diameter of the throat of the Venturi 0.00635 m (0.125 inches) and initial pH of the water of 8.5, 98.62% removal of fecal coliforms is achieved in the filtered water.

Conclusion: The maximum percentage of removal of E. coli reached was 98.62%, which is why this technique should not be considered as a single treatment for water disinfection.

Originality: In the present case, the evaluation of the CH for the disinfection of filtered water is carried out for a population that has difficulties with its supply of chemical inputs for water purification.

Limitations: Due to its jungle location, the municipality is vulnerable to the evolution and development of technological advances in regard to detailed treatments and studies in water disinfection.

Keywords: Disinfection, hydrodynamic cavitation, Cavitation cycles, Venturi.

Resumen

Introducción: El presente artículo es producto de la investigación "evaluación de la cavitación hidrodinámica a escala de laboratorio para la desinfección de agua cruda en el municipio de Florencia- Caquetá", realizado en la Universidad de la Amazonia – Sede de investigación Macagual entre 2018 y 2019.

Problema: El costo de los insumos químicos para la desinfección y la falta de personal capacitado para la operación de sistemas de potabilización, es necesario la búsqueda de alternativas que requieran menor cantidad de productos químicos, facilidad de operación para asegurar la calidad microbiológica del agua suministrada a la población.

Objetivo: Evaluar la eficiencia de un reactor de cavitación hidrodinámica en términos de reducción de concentración de coliformes fecales a escala de laboratorio para la desinfección del agua en el municipio.

Metodología: Con el objeto de explorar los resultados de la alternativa propuesta y su análisis estadístico se utiliza un diseño experimental factorial de tipo 3^2, en el cual las variables o factores fueron el pH inicial del agua filtrada y el diámetro de la garganta del Venturi.

Resultados: Indican que para menor diámetro de garganta del Venturi 0.00635 m (0.125 pulgadas) y pH inicial del agua de 8,5 se alcanza el 98.62 % de remoción de coliformes fecales en el agua filtrada.

Conclusión: El máximo porcentaje de remoción de E. coli alcanzado fue de 98,62%, razón por la cual no debe considerarse esta técnica como un tratamiento único para la desinfección del agua.

Originalidad: En el presente caso se realiza la evaluación de la CH para la desinfección de agua filtrada para una población que presenta dificultades para el suministro de insumos químicos para potabilización del agua.

Limitaciones: Por la ubicación selvática, el municipio es vulnerable a la evolución y desarrollo de avances tecnológicos en lo que respecta a tratamientos y estudios detallados en la desinfección del agua.

Palabras clave: Desinfección, cavitación hidrodinámica, Ciclos de cavitación, Venturi.

Resumo

Introdução: Este artigo é produto da pesquisa "Avaliação da Cavitação Hidrodinâmica em Escala de Laboratório para Desinfecção de Água Bruta no Município de Florencia-Caquetá", realizada na Universidade da Amazônia - Sede de Pesquisa Macagual entre 2018 e 2019.

Problema: O custo dos insumos químicos para desinfecção e a falta de pessoal treinado para o funcionamento dos sistemas de purificação, faz-se necessário a busca de alternativas que requeiram menos produtos químicos, facilidade de operação para garantir a qualidade microbiológica da água fornecida à população .

Objetivo: Avaliar a eficiência de um reator de cavitação hidrodinâmica em termos de redução da concentração de coliformes fecais em escala laboratorial para desinfecção de águas no município.

Metodologia: Para explorar os resultados da alternativa proposta e sua análise estatística, é utilizado um planejamento experimental fatorial tipo 32, no qual as variáveis ou fatores foram o pH inicial da água filtrada e o diâmetro da garganta do venturi.

Resultados: indicam que para um diâmetro menor da garganta do Venturi 0,00635 m (0,125 polegadas) e pH inicial da água de 8,5, obtém-se 98,62% de remoção dos coliformes fecais na água filtrada.

Conclusão: O percentual máximo de remoção de E. coli alcançado foi de 98,62%, razão pela qual essa técnica não deve ser considerada como um único tratamento para desinfecção de água.

Originalidade: No caso presente, a avaliação do CH para desinfecção de água filtrada é realizada para uma população que apresenta dificuldades no fornecimento de insumos químicos para purificação de água.

Limitações: Devido à sua localização na selva, o município está vulnerável à evolução e desenvolvimento dos avanços tecnológicos no que diz respeito a tratamentos detalhados e estudos em desinfecção de águas.

Palavras-chave: Desinfecção, cavitação hidrodinâmica, Ciclos de cavitação, Venturi.

1. INTRODUCTION

With the increasingly serious problems caused by the increase in human population and environmental pollution, the availability of drinking water has long been a problem of concern worldwide [41] [42]. The presence of enteropathogenic microorganisms (total coliforms, fecal coliforms "Escherichia Coli" and other microorganisms) in the water is an important risk for public health. Some of these microorganisms can cause diseases, such as salmonellosis, diarrhea, cholera, typhoid among others. Disinfection, in most water treatment plants, is carried out using hypochlorite and gaseous chlorine and sodium, substances that have proven their effectiveness over the years. In addition, these disinfectants are economical compared to new alternative water treatment technologies [1].

In the municipality of Florencia, Caquetá, the SERVAF service company (provider of the public service of aqueduct and sewerage), has three catchments, two of them on the El Dedo and El Águila streams that supply raw water to the Caldas Potable Water Treatment and the intake on the Hacha River, which supplies raw water to the Diviso Water Treatment Plant [2]. The El Dedo and El Águila streams are a fundamental part of the municipality, not only because they satisfy the demand for raw water in the Caldas Drinking Water Treatment Plant (PTAP), but also because the waters from these two sources are used for recreational purposes. Currently, the vicinity or surroundings of the streams are mostly inhabited by families that became part of the subnormal settlements of the municipality, from which domestic wastewater is discharged to the El Dedo and El Águila streams, altering the quality of this water [3].

Based on the above, the influence and impact that urban expansion has on the quality of the municipality's water resource can be inferred, a fact that hinders the availability of drinking water, and increases the cost of purification, in addition to giving rise to different social, economic, cultural and environmental conflicts [4]. Regarding the water quality of the supplying streams in the area, it was found that there is no information on their characteristics, including knowledge of biodiversity and ecology, aspects necessary to generate proposals for proper management, protection and/or recovery; likewise, alternatives for remediation and sustainable management of the basin. There are also no systems for treating wastewater that is discharged directly to urban water sources [3].

According to the problem described and the fact that the Hacha River is one of the sources that supplies raw water to the municipality of Florence, the need to find alternatives that facilitate, improve or intensify the treatment processes of raw water with the purpose of purification, in this case the disinfection of water specifically analyzed, is an absolutely necessary process to ensure the microbiological quality of the water that is supplied to communities in order to reduce risks from diseases that can be transmitted through water.

With regard to disinfection, it is necessary to note that bacteria usually tend to form agglomerates, in which the external microorganisms act as a protective barrier against biocides. Cavitation produces a declination effect, breaking up agglomerates through shock waves and isolating individual bacteria. Initially, the inflected agglomerates result in an apparent increase in the bacteria population during the early stages of cavitation. Once the groups of bacteria are broken up, the efficiency of the biocides increases [1]. In the municipality of Florencia, disinfection of water is carried out using chlorine. In this project hydrodynamic cavitation (HC) was evaluated as an alternative to enhance the disinfection process to reduce consumption of chlorine during disinfection, ensuring inactivation of micro-organisms in the water and limit the formation of chlorination by-products that can be harmful to health.

2. RESEARCH BACKGROUND

Several authors have reported the use of advanced oxidation in processes such as microwave irradiation, ultraviolet radiation and Fenton oxidation for ballast water treatment [5,6]. Although these techniques are effective for removing microorganisms from seawater, the main problems are associated with the expansion and maintenance of such processes on board a ship, installation and operation of the costs of such systems are other important issues that have not been satisfactorily addressed. Cavitation, caused by water pressure gradients due to the influence of geometry, is more specifically referred to as hydrodynamic cavitation [7,8]. While ultrasonic applications (SUs) have been researched and used for decades, intensive hydrodynamic cavitation (HC) research for use in water treatment has just started more intensively in the 1990s and has been progressing ever since. HC for water and wastewater applications are usually generated by contractions in flow (for example, Venturi) [9,10,11] or constructions in the form of nozzles, hole plates [12,13,14] and element rotation [15,16] or the like. Cavitation performance depends on the intensity of the phenomena described by the cavitation number (Cv) and the number of passes (NOP) through the cavitation generator [7,8]. The HC has been studied for disinfection purposes [1], in addition, there are different fields in which HC has been applied [1]. It has been demonstrated that hydrodynamic cavitation is an efficient technique in terms of energy consumed and operating cost for disinfecting well water and effluents [17,18], Shivram y col [19]. HC is an emerging technology that has been used for different applications and in industry, for example, for the extraction of soy proteins [20], extraction of lipids form microalgae [21], disruption of yeast cells for extraction of bioactive compounds [22], reduction of coagulating bacilli in milk processing [23], waste processing and human hair recovery [24], among others. With respect to the treatment of water, its application focuses on improving biological treatments, as it increases the biodegradability of organic matter present in water, contributes to improving anaerobic digestion of sludge by disintegration of sludge and improves sludge dewatering, etc. [25]. Specifically, the effectiveness of HC has been proven in applications that involve cell disruption and water disinfection. In addition, there are other fields in which HC is potentially useful, such as mineral flotation [26] treatment of emerging pollutants and disinfection of treated wastewater for reuse [25]. HC has been studied for the disinfection of sea water. It was found that this technique has the ability to eliminate more than 75% of zooplankton present in the water [27]. In relation to the disinfection of fresh water, the effectiveness of different designs of HC systems, which include HC induced by plates with orifices installed in the flow line, high speed homogenizers, high pressure homogenizers, valves, and Venturi tubes, has been proven and varies between 71.2% and 99.96% removal of coliforms for reaction times between 15 minutes and 180 minutes [28].

The physical and chemical effects caused by HC are often difficult to characterize. The physical effects of cavitation (i.e. the intensity of cavitation) are critically dependent on inertial forces during bubble collapse, including the creation of high temperature and pressure shock waves, thus generating hydroxyl radical reagents [1]. Theoretical studies reveal that the inertial effects and, therefore, the intensity of cavitation, increases dramatically with the parameter R_{max}/R_o (maximum radius reached by the bubble over the initial radius of the bubble) [29], and with the speed of pressure recovery [30]. In piping systems, cavitation normally occurs, either as a result of an increase in kinetic energy (through a constriction of the zone) or an increase in the elevation of the pipe [31]. Cavitation bubbles release energy in a localized way through the emission of shock waves. During the short time that the collapse lasts, temperatures that can reach 5000 K and pressures of up to 1000 atm are reached with heating and cooling rates greater than 109 K/s as well as the emission of liquid jets at speeds that can reach 400 km/h [31]. The physical effects of cavitation can be characterized through the instantaneous pressure oscillations caused by the implosion of the cloud of bubbles or analogously through the sound generated by the phenomenon. The physical effects of cavitation can be characterized through the instantaneous pressure oscillations caused by the implosion of the cloud of bubbles or analogously through the sound generated by the phenomenon [29]. With regard to the chemical effects, the extreme conditions generated at the gas/liquid interface during the collapse of cavitation bubbles can decompose water and dissolved oxygen in it to form reactive species of H^*, O^*, OH^* and HO_2^*, these species in turn interact with water to form hydrogen peroxide and other reactive oxygen species with high enough oxidizing power to mineralize pollutants and achieve water disinfection [28].

The problem associated with quality assurance of water in developing countries is a situation of particular interest from the point of view of disease and economic losses [32]. The cost of chemical inputs and the lack of trained personnel to operate the purification systems make it difficult to supply good quality water to the population. Moreover, the use of some technology has limits, in that some of the chemical inputs used in conventional processes can result in the formation of substances that may affect health under certain conditions. The starting point is to understand that it is necessary to search for alternatives that allow water to be disinfected without the use of chemical inputs; these techniques must be robust, simple to use and inexpensive [32].

HC is an alternative that combines microbubble formation, growth and collapse that occurs in milliseconds. Provides high energy densities locally, resulting in high pressure and temperature in the range of 100 bar to 5000 bar and 1000 K to 10,000 K, respectively, at millions of locations within the liquid [33]. HC can be generated simply by the passage of liquid through a constriction that results in an increase in velocity at the expense of local pressure [34]. The cavities are generated when the pressure falls below the vapor pressure of the medium at the operating temperature, subsequently, the pressure recovers with the expansion of the liquid jet and the collapse of the cavities. Cavitation in liquid depends on the size, shape, location of the body, the condition of the surface, the dimensions of the microbubble, the solid particles that make up the cavitation core, the Cavitation, Reynolds and Weber numbers [35]. This technique may turn out to be favorable and viable to apply in the context of Florencia Caquetá, since this municipality has abundant water sources, but with deficiencies in their quality for human consumption. With this study, the aim is to contribute to the development and assurance of the water quality for the inhabitants of Florence. According to the above, it is observed that HC is a technique that can be analyzed and evaluated for natural water disinfection processes due to its ease of implementation and reduction of the use of chemical inputs.

3. MATERIALS AND METHODS

The effect of the initial pH of the water and the diameter of the venturi throat (to achieve the formation of cavities in the fluid) on the reduction of the concentration of fecal coliforms in natural water, filtered at the laboratory level, was evaluated. The prototype to carry out the tests was made up of a tank with a capacity of 0.122 m^3, connected from the bottom to a Barnes brand pump of 0.5 HP (372.85 W) with 1 inch of suction diameter and 1 inch of outlet diameter, the pump discharge was made to pass through a Venturi tube in which the flow area is reduced from 1 inch to 0.5 inches, 0.25 inches and 0.125 inches according to the test carried out. The initial pH of the water was varied between 6.5, 7.5 and 8.5; a range selected in accordance with the usual pH range in drinking water treatment plants and in accordance with the pH range for drinking water established in Resolution 2115 of 2007. To perform the pH adjustment of the water at the beginning of the tests 1 M NaOH and 1 M HCl (Merckmillipore) was used, as necessary, in each situation.

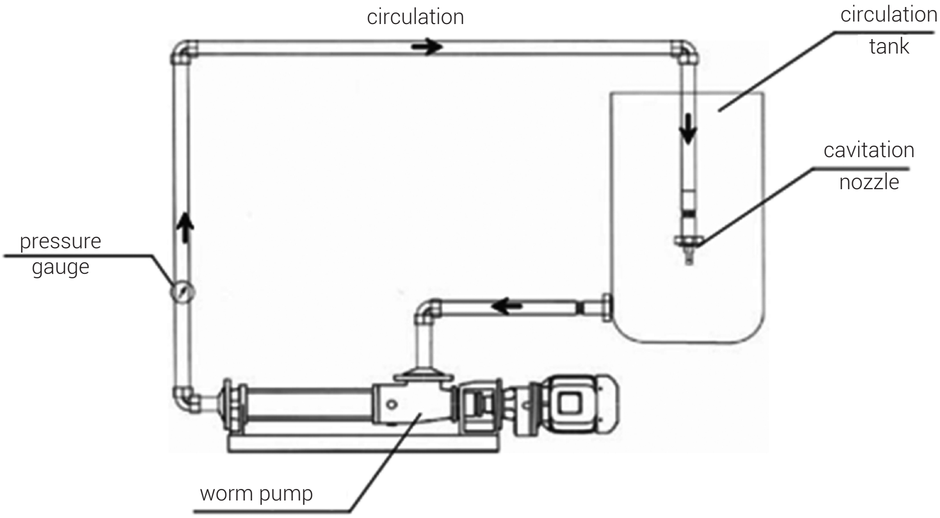

Figure 1. Diagram of the experimental configuration of the hydrodynamic cavitation reactor [37]

In the throat of each Venturi tube, the formation of cavities or bubbles takes place and the fluid is returned to the tank again to be directed to the Venturi tube and cavitate. The reaction period for the tests was 1 hour. At the beginning and end of each experiment or trial, the concentration of fecal coliforms in the water was determined and with this the efficiency of the process was calculated in terms of the percentage of removal of coliforms. The determination of fecal coliforms was carried out by the membrane filtration method established in the standard methods for analysis of drinking and residual water [36]. The analyzed water samples were taken in sterilized glass bottles and the bottles were immersed in water. Once submerged, they were uncapped to be filled and later, still submerged, the bottle was covered. Each sample was analyzed directly in the laboratory. All tests were carried out in triplicate, for a total of 27 tests.

The analysis of variance was used to determine if the variables or process factors exert an effect on the response variable and, from this, the operating conditions that resulted in the highest percentage of coliform removal were calculated and the Pareto analysis was used to establish which of the variables has or exerts the greatest influence on the response variable. Drinking water samples were obtained at the Macagual Amazon Research Center, located in Florencia Caquetá, where 0.1 m^3 (100 L) of water were taken to carry out each of the tests in the HP reactor. The reactor was operated in a discontinuous mode (batch).

4. RESULTS

In this section the results of the HC tests carried out will be presented. Table 1 shows the characteristics of the cavitation system used and the energy consumption of the pump. The tests were carried out with a single pump of 0.5 HP (372.85 W), so that the pressure before the throat of the Venturi tube was constant, since the diameter of the throat of the Venturi was varied, the number of cavitation varied, this parameter indicates that the lower its numerical value, the greater the cavitation capacity of the Venturi, that is, it will lead to a greater amount of vapor bubbles in the liquid [37].

Table 1. Data for hydrodynamic cavitation and energy consumption.

Variable	Units	Value
Reactor diameter	m	0.44
Reactor height	m	0.8
Tank volume	m^3	0.122
Volume of water in the tank	m^3	0.1
Suction and recirculation pipe diameter	m	0.0254
Operation time in each test	h	1
Pump power	kW	0.37285
Power consumption in each test	kWh	0.37285
Electric power value	$/kWh	402.82
Unit cost of treatment	$/m^3	1501.9

Source: Own work

Based on the power of the pump, the amount of energy consumed during each test was calculated, thus being able to determine the cost of the process for each m^3 of treated water. The intensity of HC is generally determined from the cavitation number; the value of this indicates if the formation of cavities or bubbles in the fluid occurs at the point of reduction of flow area. Low values of the cavitation number indicate greater probability of formation of cavities in the fluid or cavitation bubbles. This parameter is calculated from the following equation.

$$K = \frac{P_1 - P_2}{\left(\frac{\rho * v_g^2}{2}\right)}$$

In the above equation, P1 is the pump discharge differential pressure (Pa), Pv is the vapor pressure of water at process temperature (Pa), ρ is the density of water (kg/m^3) and Uw is the flow velocity in the venturi throat (m/s). As can be seen in Table

2, the cavitation number decreases as the diameter of the throat of the Venturi tube decreases. Therefore, the smaller the throat diameter, the greater the cavitation or formation of water vapor bubbles and probably the greater the effectiveness of the fecal coliform elimination process.

Table 2. Cavitation number for the different venturi throat diameters.

Venturi Throat Diameter (inches)	Cavitation Number (Cv)
0.5	1.4040
0.25	0.0878
0.125	0.0055

Source: Own work

It is widely accepted that the inactivation of cells by HC is affected by the combination of mechanical, thermal and chemical effects that cause lethal damage to microorganisms during the collapse of cavitation bubbles [28]. The mechanical or physical effect is very destructive to cells, as it causes rupture of cell membranes, changes in cell metabolism and even inactivation of cells. Cells can repair the damage when it is minor, but when the damage goes beyond the capacity of self-repair of the cells, cell lysis can occur. Thermal effects are associated with denaturation of cell membranes, loss of nutrients and ions, breakage of DNA chains, inactivation of essential enzymes, and protein coagulation. In the case of conventional thermal inactivation, microorganisms cannot survive exposures to temperatures between 70°C and 100°C or higher for a few minutes, in cavitation disinfection the collapse of the bubbles induces hot spots that reach temperatures of various thousands of degrees in the fluid which can inactivate or eliminate microorganisms. From a chemical point of view, the main reason for microorganism inactivation is the formation of OH* radicals [28].

Table 3 shows the data of the pump flow, tank volume, reaction time and cavitation cycles in each test. The number of cavitation cycles corresponds to the number of times that all the water contained in the tank passed through the Venturi tube and was subjected to hydrodynamic cavitation.

Table 3. Cavitation data

Reaction time (min)	60
Pump flow (m^3 / s)	0.0022079
Tank volume (L)	100.0
Cavitation cycles	79.5

Source: Own work

Table 4 shows the initial conditions or values of the variables or process factors for the different trials performed according to the number assigned for each trial; the trials were performed randomly.

Table 4. Experiment conditions

pH	Test number		
6.5	1	4	7
7.5	2	5	8
8.5	3	6	9
Venturi Throat Diameter (inches)	0.5	0.25	0.125

Source: Own work

The average results are presented in Table 5. There, it can be seen that the highest removal of coliforms was obtained for Test 9, in which 98.92% removal of fecal coliforms was achieved. Test 9 corresponds to the smallest throat diameter in the Venturi (0.125 inches) and pH 8.5. The foregoing indicates that, with a greater pressure drop in the throat, the formation of cavities or cavitation in the fluid favors the elimination of fecal coliforms, a fact that is confirmed by the low value of the cavitation number, which indicates that the cavitation of the fluid is significant. On the other hand, it can be indicated that for alkaline pH, the process reaches greater removal. It is necessary to point out that at the end of each test, the pH of the water increased twice with respect to the initial value, because the higher the alkalinity of the water, the faster the pH will also increase.

Table 5. Removal percentage

Test	Initial E. Coli (UFC/100 mL)	Final E. Coli (UFC/100 mL)	% removal	Average	Disinfection log
1	38	19	50.00	52.80	0.30
2	738	295	60.03	59.14	0.40
3	1120	168	85.00	84.58	0.82
4	33	13	60.61	56.87	0.40
5	1098	291	73.50	72.50	0.58
6	1833	165	91.00	90.57	1.05
7	58	15	74.14	72.44	0.59
8	3144	283	91.00	91.00	1.05
9	14570	157	98.92	98.62	1.97

Source: Own work

As a result of the treatment and in terms of disinfection log, a maximum of 1.97 log was reached, that is, 98.92% removal of E. Coli. For the evaluation of hydrodynamic cavitation reactors that use different orifice diameters, there is a design parameter that is of vital importance; this is the ratio between the total perimeter of area reduction and the flow area at the entrance of the constriction. This parameter is known as α and in the case of cavitation systems with Venturi tubes, the value of this parameter is dependent on the throat diameter [38]. When the cavitation numbers are low, the possibility of cavitation in the liquid will be much greater and with respect to the value of the parameter α, the greater its numerical value, the greater the cavitation capacity; that is, an increased amount of vapor bubbles in the liquid [36]. Cavitation can be achieved even with high cavitation numbers. From an operational point of view, the cavitation number in a HC reactor should be kept in the range of 0.1 to 1. For lower cavitation numbers, the number of bubbles produced increases per unit of time, as well as the intensity of the cavitation process [37].

In Table 6, it is observed that the factor α is greater for the case in which the diameter of the throat of the Venturi tube is 0.5 inches. This means that the hole diameter of 0.125 inches presents better characteristics for the formation of bubbles in the process, thus improving the decrease of E. Coli in the filtered water.

Table 6. Values of α and K for the tests carried out

Parameter	Hole diameter			units
	0.125	**0.25**	**0.5**	**in**
Alpha (α)	1.25984	0.62992	0.314961	mm^{-1}
Cavitation number	0.0055	0.0878	1.404	--
Cavitation cycles	79.5	79.5	79.5	--

Source: Own work

The analysis of variance was carried out from the experimental results that appear in Table 5 in order to determine if the selected variables are significant or have an effect on the response variable. The statistical analysis was performed with the average results of all the tests carried out in the laboratory-scale reactor operated in batch mode. The results of the ANOVA test establish that the percentage of removal of fecal coliforms varies according to the initial pH values of the water and venturi throat diameter; that is, the two variables are significant for the process. Table 7 contains the results of ANOVA test.

Table 7. Analysis of variance of the experimental results

Fountain	GL	SC	MC	F value	P value
Model	5	2184.83	436.97	26.54	0.011
Lineal	2	2174.19	1087.09	66.03	0.003
pH	1	1379.92	1379.92	83.82	0.003
Hole diameter	1	794.27	794.27	48.25	0.006
Attic square	2	60.76	30.38	1.85	0.300
pH*pH	1	6.26	6.26	0.38	0.581
Hole diameter * Hole diameter	1	54.50	54.50	3.31	0.166
Interaction of 2 factors	1	24.61	24.61	1.50	0.309
pH * Orifice diameter	1	24.61	24.61	1.50	0.309
Error	3	49.39	16.46		
Total	8	2234.22			
S		**R-sq.**		**R-sq. (adjusted)**	
4.05		**97.79**		94.11	

Source: own work

The ANOVA test concludes that the pH and the diameter of the venturi throat are representative and influence the percentage of removal of fecal coliforms. The ANOVA test was performed for a significance value $\alpha = 0.05$. From the ANOVA test, it is also observed that the quadratic effects and interaction between the factors are not significant on the response variable. Accordingly, the statistical model to describe the percentage of removal of fecal coliforms from the initial pH of the filtered water and the diameter of the venturi throat is a linear model for which the value of R2 is 0.9411. Thus, it can be established that both the pH and the diameter of the venturi throat affect the efficiency of the disinfection process by hydrodynamic cavitation. In terms of pH, the inactivation of bacteria is more effective at alkaline pH, possibly due to the greater presence of ion OH- that facilitates the formation of OH * radicals in the liquid. On the other hand, as indicated when calculating the cavitation number, for a smaller diameter of the venturi throat, that is, the greater the constriction of the fluid, the greater the cavitation achieved and, therefore, more bubbles that promote the elimination of pollutants through the different phenomena that occur as a consequence of cavitation.

As can be seen in Table 5, the highest removal percentage was reached for an initial pH of 8.5 and a diameter of the venturi throat of 0.125 inches; that is, in an alkaline medium and with greater constriction of the fluid. In other words, a greater cavitation number obtains greater removal of fecal coliforms. This fact coincides with what was stated by various authors on the topic who point out that the lower the cavitation number, the greater the formation of cavitation bubbles and therefore the greater influence of the different effects of destruction of microorganisms that causes the phenomenon of cavitation in water.

5. DISCUSSION

The results presented in this work are of interest, since they confirm that hydrodynamic cavitation can eliminate bacteria to the extent of 100% as desired by various standards. The cavitation process is a technique that can complement disinfection with chemical or physical agents, especially for areas in which the transport or availability of chemical-type disinfectants is complicated. The results obtained by means of HC are competitive compared to other conventional methods, and there are advantages, such as avoiding the problems associated with the use and handling of chemical products, limiting or eliminating the formation of chlorinated organic compounds that can have adverse effects on health, and independence regarding the availability of supplies for treatment.

Cavitation requires a considerable reduction in the flow area to achieve a sufficient quantity of cavities or bubbles to lead to the inactivation of pathogenic microorganisms, but the process is associated with retention times of more than one hour and at least 79 cycles; a fact that generates an increase in the energy costs of the process.

The maximum percentage of E. Coli removal was 98.62%, which is why this technique should not be considered as a single treatment for water disinfection and it is convenient to use this technique together with some chemical disinfectant with residual effect to achieve the degree of disinfection required by the regulations and to ensure the presence of a disinfectant with a residual effect.

In the case of partial destruction of bacteria by cavitation, the process can be suitably combined with adsorption where suitable adsorbents, effective for disinfection, can be employed: p. silver nanocomposites, bio-nanocomposites, etc. [39,40].

6. CONCLUSION

The process can also be used simultaneously with the injection of ozone and UV radiation to ensure the complete inactivation of the microorganisms present in the water in order to comply with the water quality requirements established by Colombian regulations.

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