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TREATMENT OF LAKES WATER CONTAMINATED BY POLYCYCLIC AROMATIC HYDROCARBONS USING HYDRODYNAMIC CAVITATION

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Polycyclic Aromatic Hydrocarbons (PAHs) are considered Persistent Organic Pollutants (POPs). The presence of these pollutants in the aquatic environment constitutes a significant danger to living organisms because they are difficult to decompose and cause cancer and genetic mutations. Therefore, they have become a concern in many countries, and effective methods must be found to remove them from the water. In this paper, the removal of PAHs in Sureat lake water was studied. Water samples were taken and analyzed using Gas Chromatography / Mass Spectrometry (GC/MS) to determine the concentrations of PAHs. The total concentration of PAHs was 508 ng/L. A hydrodynamic cavitation device was designed using the orifice plate with nine circular holes and different pressures (1, 3, 5, 7, 9 bar) were applied. Then the removal ratio of PAHs was determined at the following time intervals 5, 10, 15, 20, 25, and 30 minutes. The results showed that the removal ratio increased with increasing pressure and cavitation time. It was 7 % at (p = 1 bar, t = 5 min) and increased to approximately 100% at p = 7 and 9 bar from t = 25 to 30min. Removal ratio values were very close at (p = 7, 9 bars) at all times. So p = 7 bar and t = 25 min which corresponded to circulation degree (Lc = 20 times), cavitation number (C_v= 0. 35) and cavitational yield = $5.84*10^{-9}$ ng/j were found to be the best economic and environmental working parameters. The results highlight the importance of choosing the cavitation operating parameters to obtain maximum efficiency in removing PAHs from lakes water.

Keywords: Hydrodynamic cavitation; persistent organic pollutants; polycyclic aromatic hydrocarbons; gas chromatography; removal ratio.

1. INTRODUCTION

Population growth and industrial and agricultural development have led to the pollution of surface and groundwater sources by persistent organic pollutants (POPs) [1, 2].

POPs are toxic compounds including industrial chemicals, polycyclic aromatic hydrocarbons (PAHs),

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organochlorine pesticides, pharmaceuticals, hormones, textile dyes, dioxins, and furans [3,4].

Polycyclic aromatic hydrocarbons (PAHs) are complex compounds composed of carbon and hydrogen atoms bonded together in a linear, angular, or cluster arrangement to form strong, cohesive aromatic rings [5,6]. PAHs compounds are difficult to degrade because they resist chemical and biological decomposition. Therefore, they remain in the water for a long time and accumulate in the fatty tissues of living organisms disrupting the ecosystem [7]. In addition, the arrival of these pollutants to humans will cause cancers, genetic mutations, and birth defects [8].

There are various methods for treating water such as coagulation, filtration, adsorption, chemical oxidation, and others. But they are not effective enough in removing PAHs compounds [9, 10].

Recently, advanced oxidation processes (AOPs) have received good attention for their ability to destroy persistent organic pollutants in water [11]. Many Techniques have been used, including chemical oxidation by adding ozone and hydrogen peroxide, as well as photochemical oxidation by ultraviolet rays, in addition to ultrasound and others [12]. All of these technologies rely on the generation of free radicals that are highly reactive to pollutants [13]. Despite their high effectiveness in destroying POPs, they require expensive materials and regular maintenance in their lifetime. In recent years, hydrodynamic cavitation technology has received great attention in advanced oxidation techniques [14]. It is environmentally friendly and economical in water treatment. Cavitation technology breaks down non-degradable organic compounds into simple compounds [15]. It produces organic compounds with lower molecular mass and greater biodegradability, in contrast to the traditional treatment methods which involve the separation of pollutants. The cavitation technique does not transfer the pollution problem elsewhere, but it leads to the complete decomposition of persistent pollutants without adding chemicals or changing the basic properties of water [16]. The phenomenon of hydrodynamic cavitation occurs in the tubes in the stenosis area using a venturi tube, orifice plate, and systole valve. When pressure decreases and speed increases in the stenosis area, the cavitation bubbles are formed. Then, after sectional expansion of the tube, the pressure rises again. These sudden and large changes in pressure and speed cause the collapse of the formed cavitation. Then liquid begins to boil and harsh local conditions form in the trapped bubble with high temperatures from 1000 to 10000 K, and high pressures ranging from 100 to 5000 bar [17]. In addition to generating highly reactive free radicals such as H*, and HO*. These free radicals are highly reactive and the strongest oxidants that are responsible for breaking down PAHs into simple compounds can be disposed of by conventional treatment [18,19,20]. Based on the above, hydrodynamic cavitation can be considered a promising technology in water treatment.

This paper aims to study the possibility of using the hydrodynamic cavitation technique to remove PAHs from Sureat Lake water. The hydrodynamic cavitation system was designed using the orifice plate with nine holes and operated in the laboratory. Different pressures were applied and the percentage of removal of PAHs compounds was determined after successive periods to obtain the optimum operating parameters of the hydrodynamic cavitation technique.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Sureat Lake is located in Lattakia in Syria as shown in Fig. 1(a). It is surrounded by agricultural lands as shown in the satellite image Fig. 1(b). Agriculture is the main occupation spread in the feeding basin of the lake and a lot of greenhouses and orchards of lemon, olives, and tobacco are found. For the success of these crops, large quantities of agricultural pesticides, sterilizers, and fertilizers are used. These activities have contributed to the arrival of pollutants in the lake [21].

2.2 Sample Collection, Extraction, and Analysis

Water samples were collected from Sureat Lake in March 2021. Temperature and pH were determined. Subsequently, samples were kept in opaque glass containers that previously were cleaned with organic solvents (regular hexane and dichloromethane). The samples were extracted directly by the extraction method (liquid-liquid) using 80 ml of a mixture of two systemic organic solvents (Hexane: Dichloromethane) in a ratio of (1:1). Then the organic extracts were concentrated using a rotary evaporator to (10 ml) then a nitrogen gas to (1 ml) to be ready for the separation and purification process [22]. Thereafter, organic extracts were analyzed quantitatively and qualitatively by using the technology of gas chromatography (GC-MS) to determine the PAHs concentrations in the laboratories of the Higher Institute of Marine Research at Tishreen University in Syria.

2.3 Hydrodynamic Cavitation Device Design

The cavitation reactor is the basic design of the treatment system. A cavitation device works on circulating water in a closed loop by using a centrifugal pump characterized by the following specifications (type PE90, Foras, Italian-made, 2800 rpm, 1 horsepower, 0.74 kW). The pump draws water from the treatment tank to the main pipe to be passed through the orifice plate. Then water is discharged again back to the tank at a level below the water to avoid any agitation of air in the system. The diameter of the delivery line of the centrifugal pump is 1 inch. The other components of the system include control valves, a cavitation reactor, and pressure gauges. The tank is provided with a cooling cover to keep the water temperature constant during the system's operation. The hydrodynamic cavitation device was designed by the authors shown in (Fig. 2). The cavitation reactor is an orifice plate with a total diameter of (25.5 mm) and a thickness of (2 mm) and it has nine circular holes with a diameter (of 2 mm). The orifice plate is installed into a control valve that is used for easy replacing the plate with another one. Most of the reactor components are made up of stainless steel.

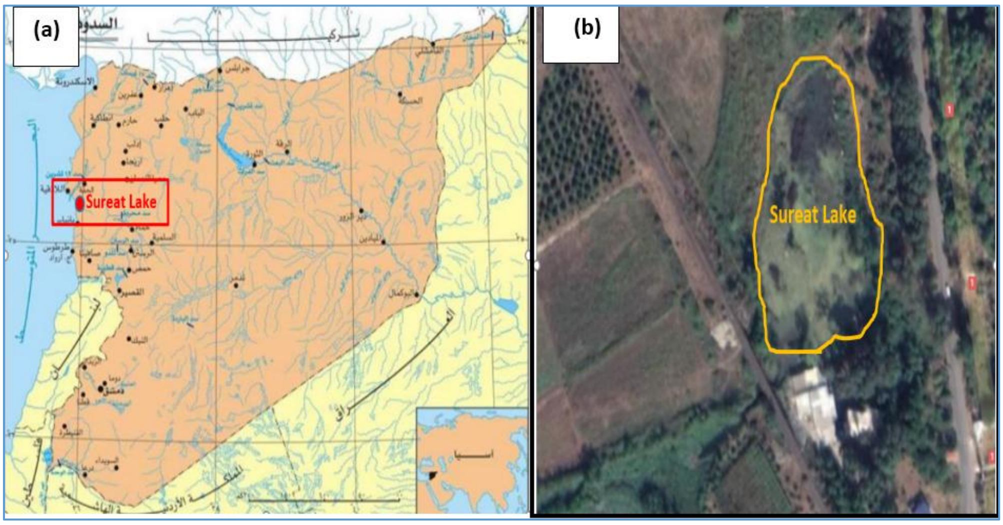

Fig. 1(a). The location of Sureat Lake on the map. (b). Satellite image of Sureat Lake in Syria

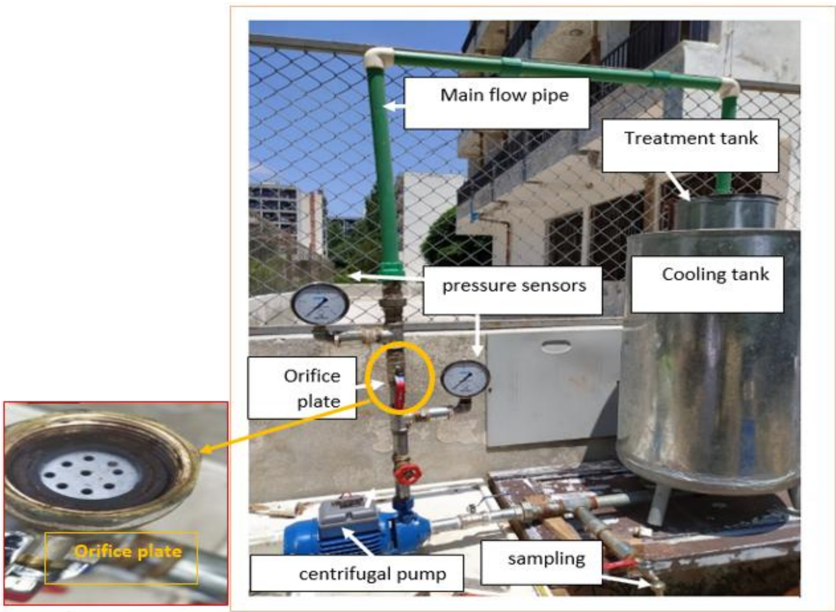

Fig. 2. Picture of the designed hydrodynamic cavitation device used in this research
The orifice plate is installed inside the control valve

2.4 Operating the Hydrodynamic Cavitation Device

Water samples were taken from Lake Sureat in March 2021. The total concentration of polycyclic aromatic hydrocarbons, temperature, and pH were determined. The concentrations of the total PAHs compounds were studied as a total sum of the concentrations of their original components (2-6) aromatic rings, which facilitates the process of comparison and interpretation of the results according to the total amount of PAHs compounds present in the samples. The values were (∑PAHs = 508 ng / L), (temperature = 15,8 ° C), and (pH = 7.12). The treatment tank was filled with (35 L) from this water. Thereafter the pump was turned on and water samples were taken after successive times of 5, 10, 15, 20, 25, and 30 minutes. Then the total concentration of (∑PAHs) was determined after each time. Experiments were carried out when applying different inlet pressures of the pump in the range (of 1 to 9 bar) and their effects on the decomposition of ∑PAHs were studied during the cavitation time.

The amount of PAHs decomposition in the cavitation process depends on two important parameters, the cavitation intensity and the number of occurrence times during the processing time. They are expressed by the Cavitation number C_v and the circulation degree Lc [8,9,10].

2.5 Cavitation Number

The cavitation number expresses the hydraulic state that occurs when the water is flowing in the holes of the orifice plate. It is given in Equation (1) [14,17]:

$$C_v = \frac{P_1 - P_2}{\frac{1}{2} \times \rho \times {V_0}^2} \tag{1}$$

where: P_1: pressure in the undisturbed flow (Pa), P_2 :vapour pressure (Pa), ρ : density of water (kg/m³), and V_0: Water velocity through the hole (m/s).

2.6 Number of Cavitation Occurrences

The number of times water cycles (circulation degree Lc) are returned through the holes greatly affects the percentage of (∑PAHs) removal during the operating time. Circulation degree is defined in Equation (2) [14]:

$$L_C = t \times \frac{Q}{V} \tag{2}$$

Where t: cavitation time (Sec), Q: Volumetric Flow of the Pump (m³/s), and *V*: Water volume in treatment tank (m³).

2.7 Processing Efficiency Evaluation

Treatment efficiency expresses the percentage of (∑PAHs) removal and is equal to the percentage change in the concentration of compounds after treatment time to their initial concentration before treatment and is given with the Formula (3) [14,19]:

$$(\%)\ E = \frac{C_0 - C_t}{C_0} \tag{3}$$

where: C_o : Initial Compounds Concentration (ng/l), and C_t : Concentration of compounds after treatment time (ng/l).

2.8 Cavitational Yield

Evaluation of the energy efficiency consumed during the cavitation process is a very important factor for calculating the processing cost. Therefore, the cavitational yield is calculated, and it represents the decrease in the concentration of (∑PAHs) compounds during the time of the electrical energy supplied to the system. It is expressed in the equation (4) [14].

$$Cavitational\ yield\ (ng/j) = \frac{amount\ of\ (\sum PAHs)\ degraded}{H \times \rho \times g \times Q \times t} \tag{4}$$

where *H*: Head (m), *ρ:* density of water (kg/m³), *g:* gravitational acceleration (m/s²), *Q:* Volumetric Flow of the Pump (m³/s), and *t*: cavitation time (Sec).

3. RESULTS AND DISCUSSION

3.1 Effect of Inlet Pressure on the Degradation (∑PAHs)

Inlet pressure is an important operational parameter in a hydrodynamic cavitation system. The results showed that (∑PAHs) removal percentage increased with an increase in the cavitation time and inlet pressure as shown in (Fig. 3). It was observed that (∑PAHs) removal percentage increased at pressure 1 bar from 7 % to 35 % when the cavitation time increased from 5 min to 30 min. Also, it continued to increase with increasing pressures from 3 to 9 bar at all times. It was observed that there was a great convergence in the removal ratio at pressures 7 and 9 bar, and this ratio was approximately 100% from t = 25 to 30 min. So p = 7 bar and t = 25 min can be considered the optimal environmental and economic parameters for operating the hydrodynamic cavitation system. The increase in the removal rate with increasing inlet pressure can be explained by the large collapse of the bubbles formed and the generation of a lot of free radicals, which react strongly with pollutants [18,19]. These results are consistent with other research which showed that the removal rate increased with increasing inlet pressure and cavitation time [14, 18].

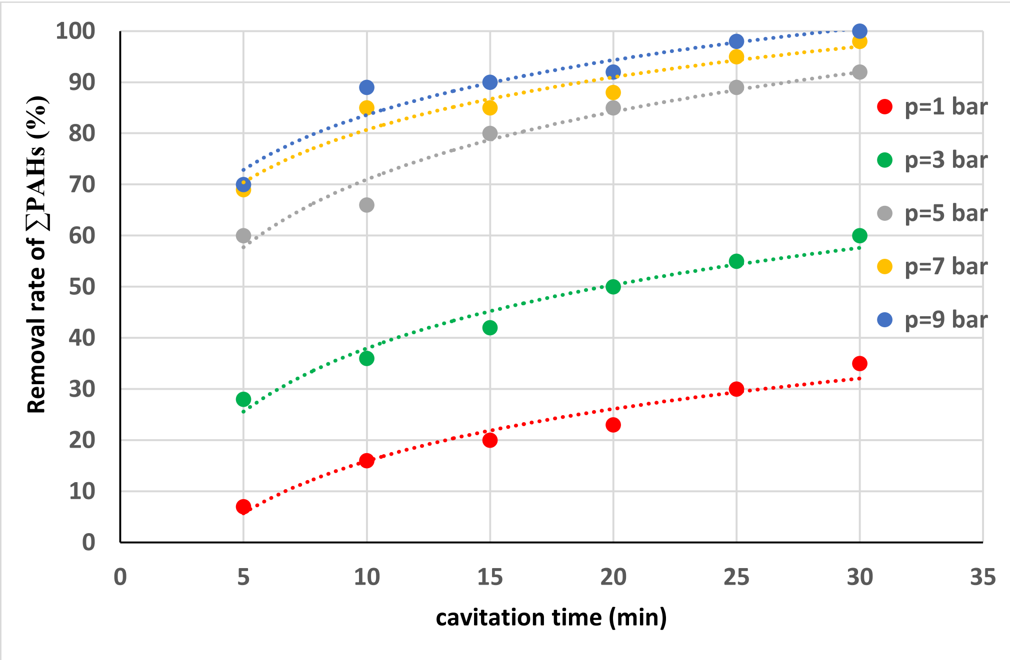

Fig. 3. Changes in the percentage of (∑PAHs) removal with changes in pressure values and cavitation time

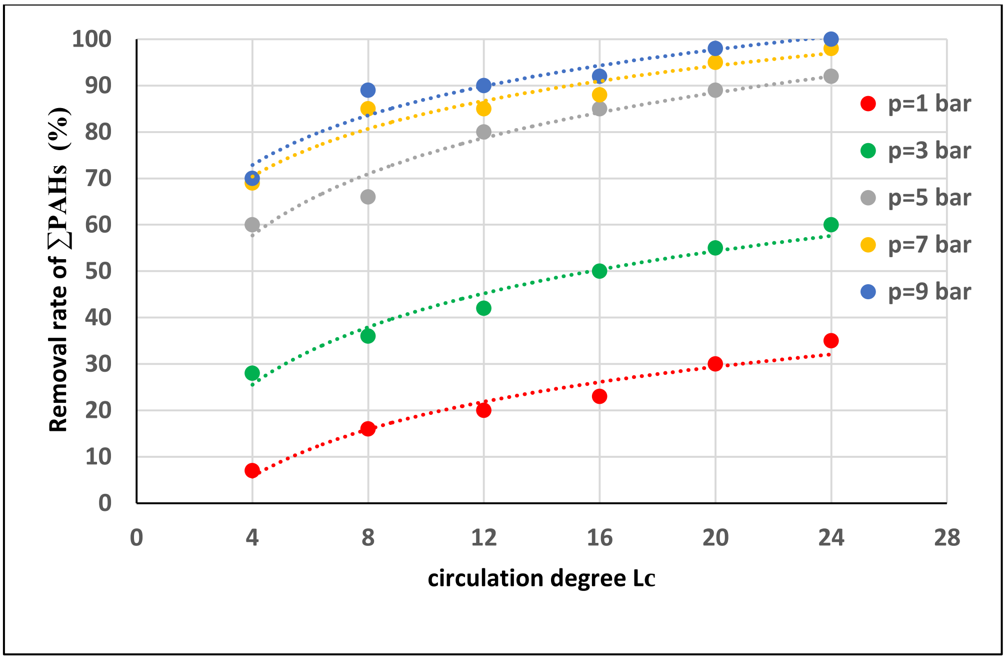

Fig. 4. Changes in the percentage of (∑PAHs) removal with changes in pressure values and circulation degree Lc

3.2 Effect of Circulation Degree Lc on (∑PAHs) Removal

The number of water circulation times through the cavitation process has a primary role in breaking down compounds and calculating the cost of treatment [14].

The results showed that (∑PAHs) removal percentage increased with increased the number of times of rotation of treated water (circulation degree Lc) in the cavitation system as shown in (Fig. 4). It was observed that (∑PAHs) removal percentage increased at pressure 1 bar from 7 % to 35 % with circulation degree increasing from Lc = 4 to 24 times at t = 5 to 30 min. Also, the removal percentage continued to increase with an increased number of rotation times at all pressures and approached 100 % starting from Lc = 20 to 24 times at pressure 7 and 9 bar. It was also observed that the removal ratio was approximate with 7 and 9 bar at all rotation times. So pressure = 7 bar and Lc = 20 times are the best choice parameters for removing (PAHs).

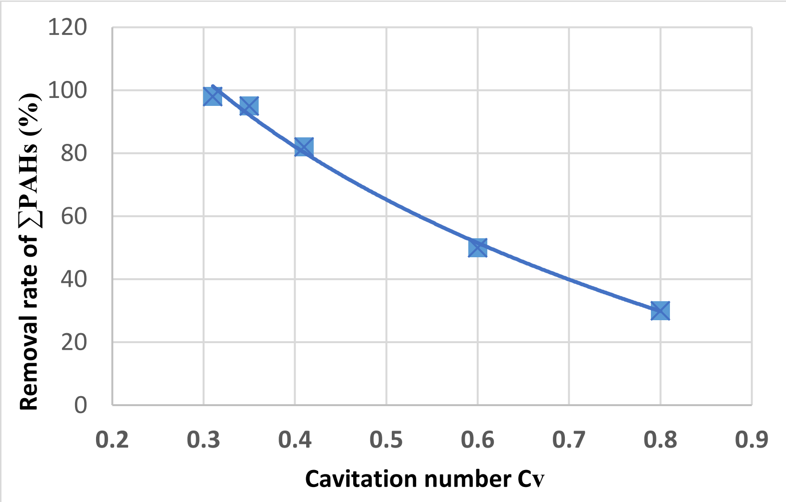

Fig. 5. Changes in the percentage of (∑PAHs) removal with changes in cavitation number C_v for circulation degree (Lc =20) and variable pressures

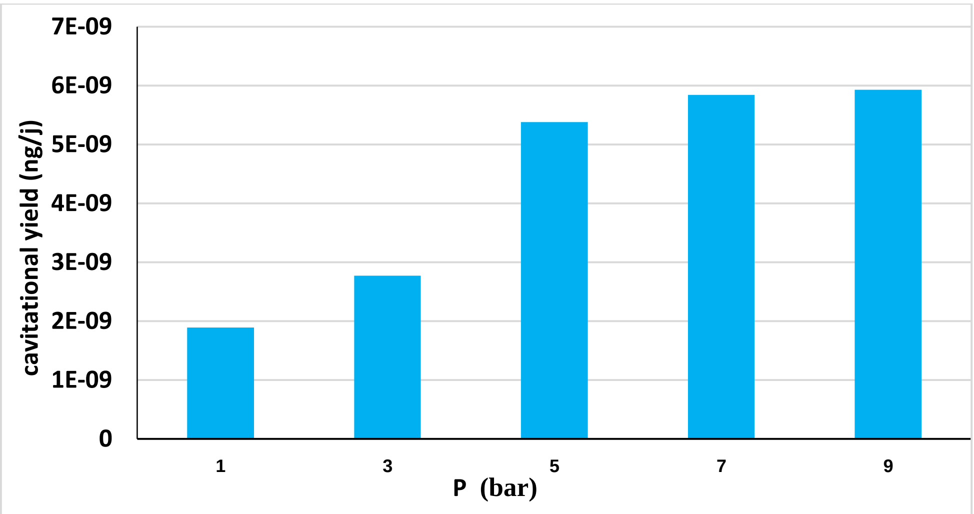

Fig. 6. Changes in the cavitational yield of (∑PAHs) removal with changes in pressure values, t = 25 minutes

3.3 Effect of Cavitation Number (C_V)

Increasing the applied inlet pressure leads to changes in the intensity and density of the cavitation. The cavitation number represents the changes in pressure and speed before and after the orifice plate [17,18]. Cavitation number is calculated by Equation (1), where $P_2 = 101325Pa$ P_1 = 2340pa, and V_0 =water speed in holes approval for each applied inlet pressure. It was observed the removal ratio increased with decreasing cavitation number at the circulation degree Lc = 20 times for all pressures as shown in (Fig. 5). It can be noticed that the removal ratio increased from 30 % to 98% when the cavitation number decreased from 0.31 to 0.8. It can be explained that increasing the pressure increases the cavitation intensity which decreases the cavitation number [14,15,16]. The results are compatible with other studies which referred that the removal ratio increased with decreasing cavitation number [23,24].

3.4 Cavitational Yield

The cavitational yield expresses the ratio of ∑PAHs degradation to the electrical energy required during the operation time [14,24,25]. The results showed an increase in cavitational yield with increasing pressures. Their values increased from $1.89*10^{-9}$ to $5.93*10^{-9}$ when the pressures increased from 1 to 9 bar at t=25 min as in (Fig. 6). It can also be seen that the cavitational yield is approximately at 7 and 9 bar. Therefore, p = 7 bar can be considered the best economically.

4. CONCLUSIONS

The results of the research showed the effectiveness of the hydrodynamic cavitation technique in removing PAHs from the waters of Sureat Lake. The percentage of removal of PAHs compounds reached approximately 100 % at the cavitation time = 25 min and pressure = 7 bar. The cavitation number = 0.35 and the circulation degree =20 times. These parameters achieved a high cavitational yield, which indicated the high efficiency of the cavitation technology in removing PAHs from the water. Therefore, cavitation technology can be considered promising and effective in removing POPs. There is a need for a more comprehensive investigation of other persistent organic pollutants in water, an assessment of their risks, and a study of the possibility of removing them by hydrodynamic cavitation.

Therefore, we recommend further research in this field, using different designs of cavitation reactors, changing the operational parameters of the system, and applying them to water with other pollutants.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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