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and Scientific Research  
University of Babylon  
College of Education for Pure Sciences  
Department of Physics**

# **The Performance of Nano Bubbles when Hydraulic Pressure and Temperature by Change in Fresh Water**

**A Thesis**

**Submitted to the Council of College of Education  
for Pure Sciences / University of Babylon in Partial Fulfillment  
of the Requirements  
for the Degree of Master in Education/ Physics**

**by**

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**1443 A.H**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

﴿ وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ ﴾

وَالْمُؤْمِنُونَ <sup>ص</sup> وَسُتْرُدُونَ إِلَىٰ عِلْمِ الْغَيْبِ وَالشَّهَادَةِ

فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ تَعْمَلُونَ ﴿١٠٥﴾

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***Dedication***

***To the savior of the nation and the savior of humanity from ignorance  
to knowledge, our master and intercessor, Abu al-Qasim Muhammad  
“may God bless him and grant him peace”***

***To the best woman in the universe..... my mother***

***to those who left my world..... my dear father***

***to those who taught me that life without interdependence, love and  
cooperation is nothing..... my brothers Hussein, Muhammad baqer***

***To the soul partner and the closest to her..... my beloved husband.***

***To the three roses.... my dear children***

***to my close friends***

***to my teachers***

***and everyone who helped me***

***Zainab*** 

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*Special Thanks to the Deanery of the College of Education for the Pure Sciences/ University of Babylon and the Department of Physics for offering me the opportunity to complete my research. I also would like to express my grateful thanks to all teachers, instructors and students of the department of physics for their assistance.*

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*Zainab*

## ***Abstract***

The nano bubbles were generated through a mechanical system that contains three stages, which is the generation of large-sized bubbles using a venturi device, by means of Bernoulli's rule in different pressures.

Then it begins to convert the small bubbles produced by a reverse direction water pump into microscopic bubbles, then convert them through a nanobubble generating device that contains inverting tubes and reversible fans, which produces a mixture of nano and micro bubbles.

Ranging in diameters (80-200nm) with respect to the bubbles for the nanobubbles , (200-1200  $\mu\text{m}$ ) for micro bubbles. Then, the presence of nanobubbles was proven by means of the D. O correction device, which reaches the ratio of dissolved nan bubbles up to 29 mg / liter in fresh water, and we have found a new method for calculating the percentage of dissolved nanobubbles by means of an optical spectrophotometer that works with ultraviolet rays with a wavelength (180-1180 nm) ) As the reflectivity was distinctive in water containing nanobubbles than in normal fresh water.

The relationship of reflectivity is positive with an increase in the presence of dissolved nanobubbles in the water, and the best output of the water flow was at a pressure ranging between (1.9-0.7 MPa). It was found that these changes are consistent with the theoretical study of the change of the surface area of the nanobubbles.

The smallest diameter of the bubble is obtained at pressure (1,820 MPa). Also, the relationship between the radius of the nanobubbles and the amount of flow is positive, as a radius of about 80 nm was obtained when the amount of flow was 0.02.

The velocity of the bubble also increases with the increase in the amount of flow. Also, we get the largest radius when the size of the bubble is about  $34 \times 10^{21} m^3$ .

The time it takes to cool and heat the water that contains nan bubbles and normal fresh water was also measured, as the results showed that the water that contains nanoscale bubbles takes less time to cool and thus It can be used in cooling appliances.

And through the process of heating water (20-80 °C), it was found that the relationship between the time period of the nanobubbles buoyancy and their escape from the water is inversely proportional to the increase in temperature

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## List of Symbols

<i>Symbol</i>	<i>Description</i>
<b>P</b>	<b>Partial Pressure</b>
<b><math>P_i</math></b>	<b>The pressure Inside the Bubble</b>
<b><math>P_o</math></b>	<b>The Pressure Outside the Bubble</b>
<b><math>K_h</math></b>	<b>Henry Constant</b>
<b>C</b>	<b>Gas Concentration</b>
<b><math>V_s</math></b>	<b>Viscosity</b>
<b><math>P_g</math></b>	<b>Gas Pressure</b>
<b><math>P_L</math></b>	<b>Liquid Pressure</b>
<b><math>v</math></b>	<b>Velocity</b>
<b>g</b>	<b>Gravity</b>
<b><math>d^2</math></b>	<b>Diameter</b>
<b><math>\rho_g</math></b>	<b>Density of Gas</b>
<b><math>\rho_L</math></b>	<b>Densities of liquid</b>
<b><math>t</math></b>	<b>Lifetime</b>
<b>R</b>	<b>Ideal Gas Constant</b>
<b>T</b>	<b>Temperature</b>
<b>D</b>	<b>Diffusion Constant</b>
<b><math>a_v</math></b>	<b>Specific of Area</b>
<b>D.O</b>	<b>Dissolved Oxygen</b>
<b><math>T_o</math></b>	<b>Transmittance</b>
<b><math>F_s</math></b>	<b>Surface Force</b>
<b><math>F_b</math></b>	<b>Body Force</b>
<b><math>K_B</math></b>	<b>Boltzmann's Constant</b>
<b><math>D_o</math></b>	<b>Positional of the Fluctuation Brownian Particle</b>
<b>A</b>	<b>Absorbance</b>
<b>M</b>	<b>Mobility</b>

$\zeta$	<b>Zeta Potential</b>
$\epsilon_w$	<b>Relative Permittivity of Water</b>
$\epsilon_o$	<b>Relative Permittivity of Free Space</b>
$R_o$	<b>Reflectance</b>
$I_o$	<b>Intensity of the Incident Rays</b>
$I_R$	<b>Intensity of the Rays Reflecting</b>
$I_A$	<b>Absorbed Light Intensity</b>
$\gamma$	<b>Surface Tension</b>
<b>G</b>	<b>Free Energy</b>
<b>R</b>	<b>Radius</b>
<b>W</b>	<b>Work</b>
<b>V</b>	<b>Volume</b>
<b>A</b>	<b>Area</b>
<b>M</b>	<b>Number Mach</b>
$\gamma$	<b>Interfacial tension</b>

## List of Abbreviation

<b>Abbreviation</b>	<b>Physical Meanings</b>
<b>UV</b>	<b>Ultra Violet</b>
<b><math>\nu_{is}</math></b>	<b>Visible Light</b>
<b>ADF</b>	<b>Dissolved Air Flotation</b>
<b>SCOD</b>	<b>Soluble Chemical Oxygen Demands</b>
<b>MBG</b>	<b>Micro Bubble Generator</b>

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# ***Chapter One***

### **1-1 Introduction:**

Nanobubbles or micro-bubbles are gaps of gases with a diameter of less than 200 nm in aqueous solutions [1]. The industrial application of nanobubble bubbles has increased dramatically over the past two decades due to their interaction and stability, compared to large bubbles and microscopic bubbles, due to their size, they are characterized by high surface areas with limited and high stay times [2, 3].

This increases its efficiency, physical absorption and chemical reactions at the surface of gas and liquid, as these bubbles have a long residence time in solutions and electrically charged surfaces[8]. Given the above, nanobubbles have many applications for industrial purposes such as removing soil and sediment contamination, drug delivery, and sterilization of food products [4].

Nanobubbles were also found in aqueous solutions for several weeks. Moreover, it was reported that bubbles with a radius of 150-200 nanometers were in a state of dissolution within two weeks [5]. The electrically charged bubble creates repellent forces that prevent the bubbles from sticking, thus, high bubble densities create high concentrations. gases dissolved in water forming smaller concentration gradients between the interface and the liquid [6]. Therefore, the stability of the bubbles increased due to the low velocity, which is negligible due to the brownish motion and the low buoyancy forces [1].

Among other reasons, the nanobubbles are stable through mutual protection against the diffuse flow of gases, which can be achieved if the bubbles are close together sufficiency of each other or grouped into groups of micrometer size [7].

The existence of stable secondary bubbles has been confirmed experimentally, however no clear theoretical foundations have been established to understand their long-term stability, knowledge of their properties and behavior is very important, however the behavior of nanobubbles is complex, so further study is needed for a clear understanding of the stability of nanobubbles. , which is affected by the generation techniques, fusion and generation of free radicals, and the factors affecting the stability of nanobubbles such as temperature,

pressure, salt concentration, and so on in many fields of science, technology and industry [4].

### **1-2 Applications:**

Nanobubbles have many applications such as drinking water and wastewater treatment. They are also used in groundwater disinfection, medicine, and other applications such as industry, fish farming, and agriculture [31]. Treating sewage and drinking water is one of the best uses of nanobubbles. It was recently developed due to its ability to generate highly reactive free radicals [9, 10]. The groundwater was treated with fine ozone bubbles[11]. A new technique for shattering sediments using ultrasound nanobubble ozone bubbles has been proposed [12]. The use of three innovative technologies, namely, ozone, ultrasound and nanobubbles, to provide a low total cost treatment over a shorter period of time [4].

Since it has little negative impact on the environment and the economic and social growth of the area, the ultrasound energy provides cleaning of the sediments. Just as ozone reacts with absorbed pollutants and removes them from the water, nanobubbles also help dissolve ozone in water [13, 12].

The purpose of using nanobubbles is their experiments to spare air [14,16], and there are many biomedical applications of nanobubbles, such as drug delivery to human organs and ultrasound diagnostics of cavities, as cancerous tumors are treated using nanobubbles, nanobubbles are placed in the body and when they approach cancer cells, the nanobubbles burst, which leads to the destruction of cancer cells [17]. It is also used in emergency procedures. The bloodstream, which allows patients suffering from asphyxia for an additional 15 minutes while they are hospitalized, although it is not long, it allows for a higher survival rate [8].

The gas exchange between the atmosphere and the ocean is another feature of bubbles in nature. Bubbles, both small and large, have a significant effect on the breakdown of greenhouse gases, including CO<sub>2</sub>, in sea water, and thus must be considered in climate and ocean acidification science [18].

There are many industrial applications of nano bubbles. The nanobubbles have shown the ability to form reactive oxygen species that contribute to seed germination, and the increase in reactive oxygen species has the same effect as H<sub>2</sub>O<sub>2</sub>, which leads to higher germination rates [19]. Nanobubbles are used to reduce agricultural pesticide residues [20]. It is also used in sports drinks and soft drinks. By adding nano bubbles, water can hold gases for a longer period [21].

Nanobubbles are used in coatings due to the presence of nanobubbles, as the coating dries faster and is also resistant to mold. In addition to the increased brightness due to the presence of nanobubbles [22]. Also, nano bubbles are used as an artificial float in the water. This is achieved by changing the ionic balance of ions dissolved in liquids and changing the net charge on the surface of the particles [23]. In the food industry, nano bubbles are used to regulate the pH levels in liquids containing carbon dioxide, by adding nano-bubbles CO<sub>2</sub>, which are suspended in water for a long time to regulate the pH of the solutions [24]. In fish farming [25].

Studies have also shown that any decrease in the level of oxygen leads to a decrease in feeding and respiration activity and a slowdown in the rate of fish growth [26]. But with air and oxygen nanobubbles, water levels and fish survival rates are kept high [25]. They are used in oil / water emulsion treatment [27], gas / liquid conductors and algae separation [28] as well as free radical generation [29] and are suitable for applications. Specific details such as reducing the drag force in piping flow [30].

### **1-3 Technology for Generating Micro Bubbles in Liquid:**

There are a number of techniques and mechanisms available for producing small bubbles (micro and nano) in liquids in light of rising demand, the commercialization of wastewater treatment and disinfection systems, among other items. Small bubbles are usually created in a liquid using one of two methods:

1- A constant flow rate of gas is introduced into the stationary liquid [32].

2- The gas is dissolved in the liquid, and the liquid-gas mixture is automatically / hydraulically introduced into an unstable state (turbulence) to create tiny bubbles the Method divid[32] .

### **1-3-1: Venture Type:**

The venture type in generating infinitesimal (minute) bubbles depends on the common continuity equation, which states that mass is preserved. This means that the rate of mass flow outside and inside any system must be equal unless there is an energy discharge or in the form of leakage or chemical reaction, the three main sections of a venture tube. It consists of a converging inlet and creating the suction and finally the outlet manifold system, as the section converges to the lowest region in the throat, a low pressure area is created, and air (gas) is absorbed through the suction collector.

As a result, water flows in two stages with air (gas). traverse the remaining section of the venture tube where bubbles are generated due to the shear forces encountered in the diverging part . but this method is not effective in producing micro bubbles and nano bubbles as it works to produce bubbles up to the millimeter. In addition to gas injection or cavitation principles, the de Laval nozzle underlies the phenomenon and provides the acoustic properties of liquid flow.

Since the water is incompressible, the two-phase flow adds parameters of compression that must be taken into consideration. A prerequisite in the piping section is throttling in order to achieve an accelerated row during the flow course. So that the flow in the converging part is basically less than the speed of sound through and through the quality in the throat, until the suffocation is reached that is, the number Mach, and when a supersonic field is created in the manifold part it is mandatory because it forms microscopic bubbles due to shear from the shock waves that were designed in this part [33] as in figure (1.1).

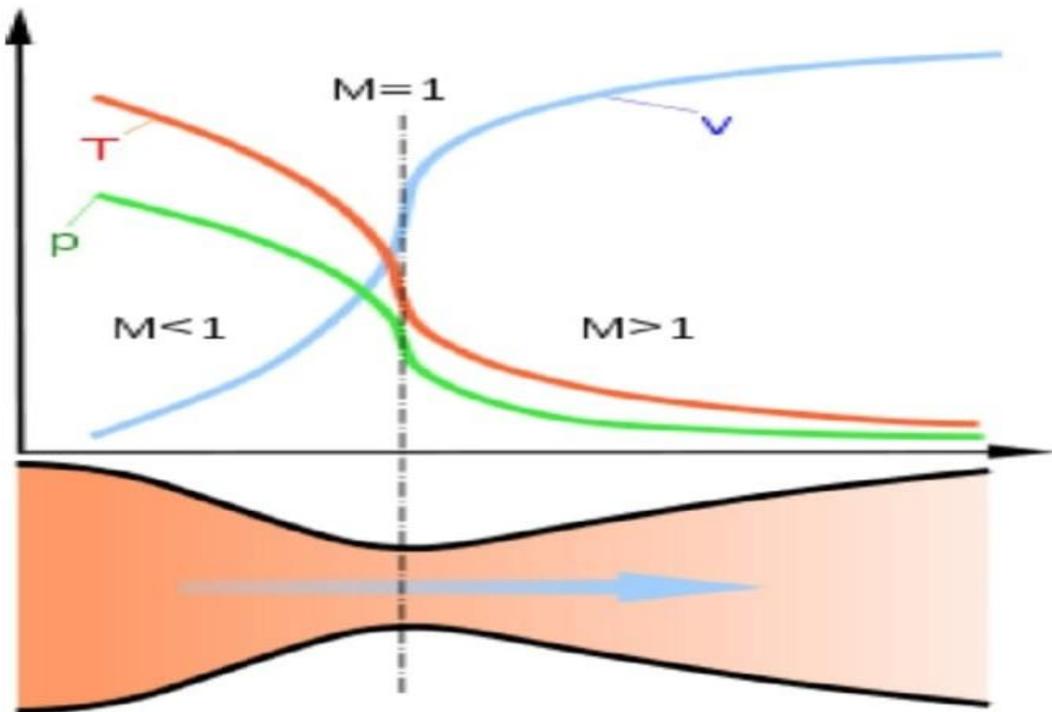


Figure (1-1) Venture flow combined with the state of the nozzle condition [33].

### 1-3-2 Decompression (compressed atomization):

The device for producing micro-bubbles for pressurized melt is based on Henry's law (which relates a gas's partial pressure to its concentration) and that Henry's rule is written as follows[78]:

$$C = K_h P \dots (1-1)$$

where  $C$  is the gas concentration,  $P$  is the partial pressure, and  $K_h$  is the Henry constant. Where Henry's Law states (that a lot of gas can be dissolved at high pressure in the solution).

Compressed air is introduced into the water tank in a pressurized micro-bubble generator.

Due to the large decrease in the pressure of the supersaturated water, air is released in the form of small bubbles in the stream using this scientific method. This principle is illustrated in Fig (1.2) [33].

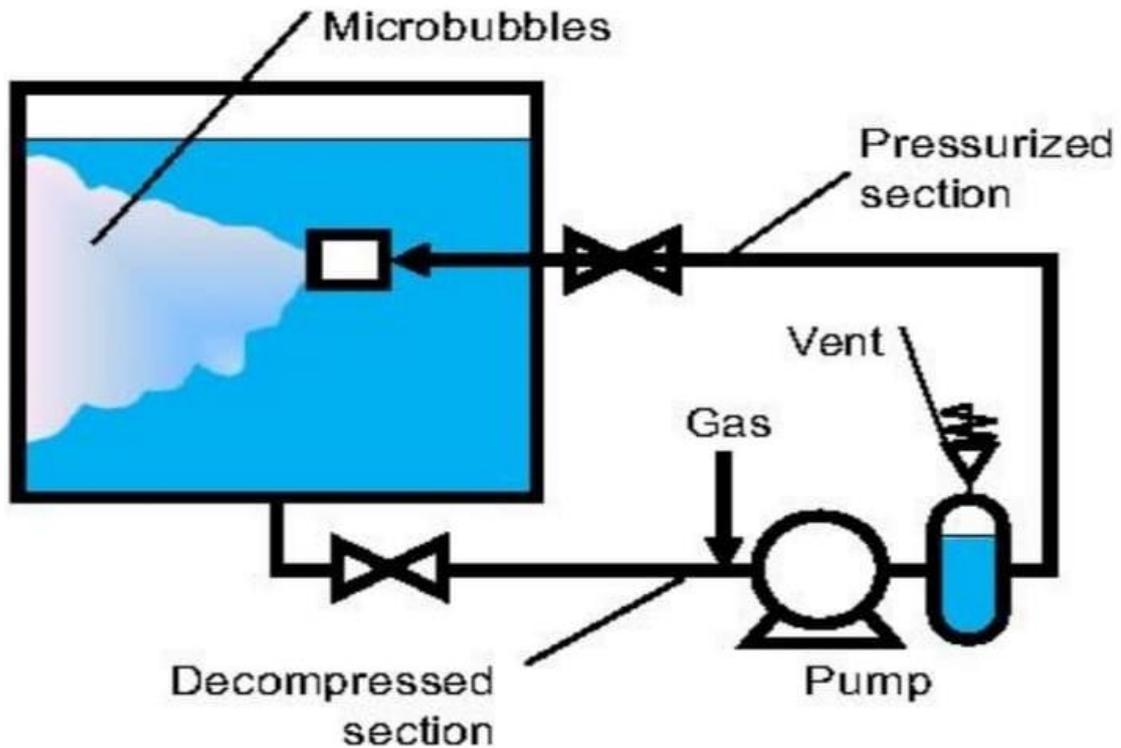


Figure (1-2) Pressurized Dissolution Form [39]

### 1-3-3 Spiral liquid flow type (rotary type):

One of the widely used and well-patented technologies known to Japanese researchers is the vortex type or microsphere generator the cyclone fluid flow type [33]. The theory is simple and it follows that the work of a central core to a low pressure similar to a vortex. As water is fed into a cylindrical tank, air (gas) is drawn from the bottom hole and allowed to flow in a spiral pattern that crosses the inner diameter of the cylinder. To produce tiny bubbles, air is blown together with the water absorbed by the top. As seen in the illustration (1.3) [35].

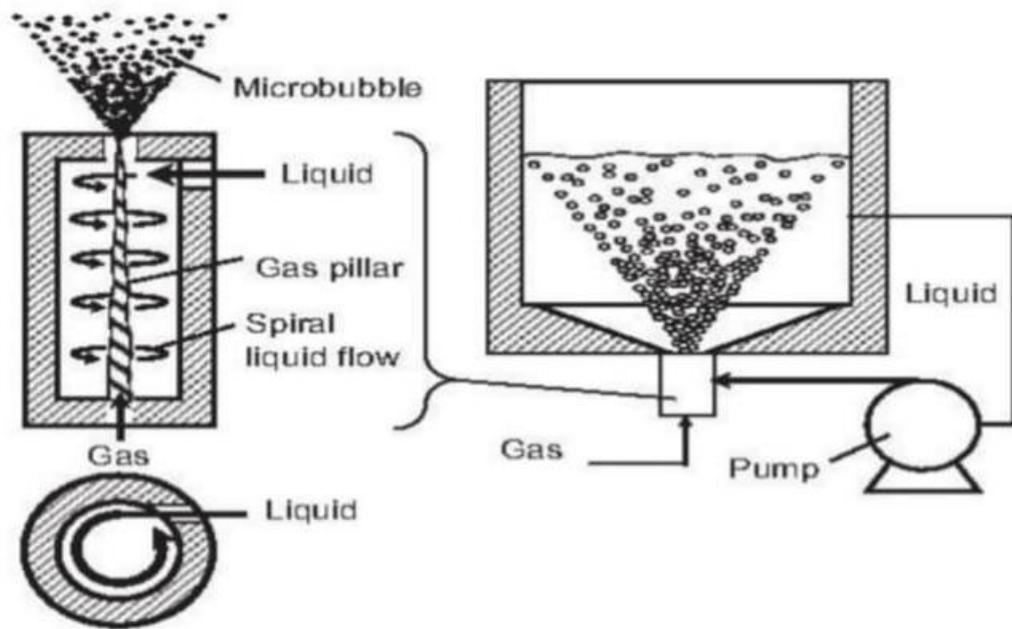


Figure (1-3) micro-bubbles generator of the swirl liquid flow sort [35].

### 1-3-4 Form of ejector (complex pressure profile):

The adventurer's tube micro-bubble generator is almost similar to the ejector-type micro-bubble generator in terms of speed and compression. The ejector form has been used in several comparisons with predecessors, despite not being the first option. [36]. Figure (1.4) represents an ejector-type bubble generator. Sprinklers or a combination of them are often used to generate small bubbles, in addition to systems based on four basic techniques for generating microbubbles [37]. Other designs for generating microscopic bubbles, such as those designed by sadatomi [29], are a modification of the conventional venture tube structure. Where a spherical body is surrounded midway through a rectangular part surrounding the flow of water as shown in Figure (1.5). The spherical body helps to reduce the pressure necessary to produce the tiny bubbles through the gas hole in order to absorb the gas and cut it with the water in the exit section [39].

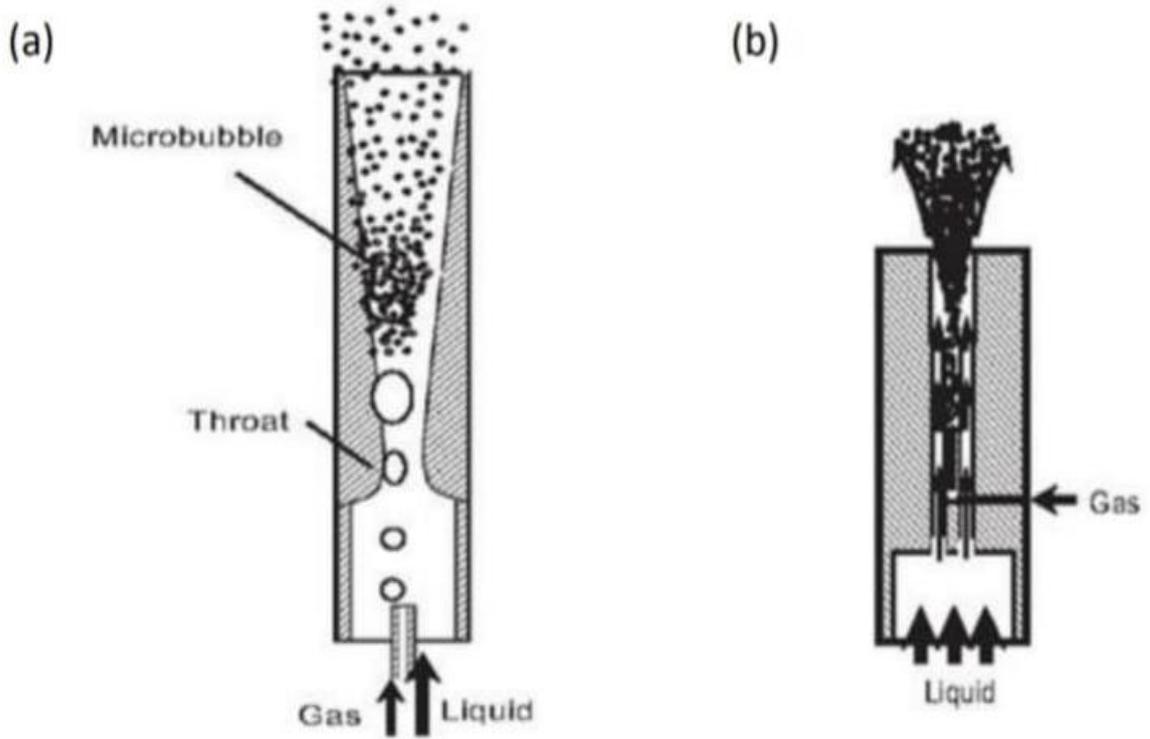


Figure (1-4) (a) Micro-bubble generator for venturi-type  
(b) Microbubble generator with ejector-type[39]

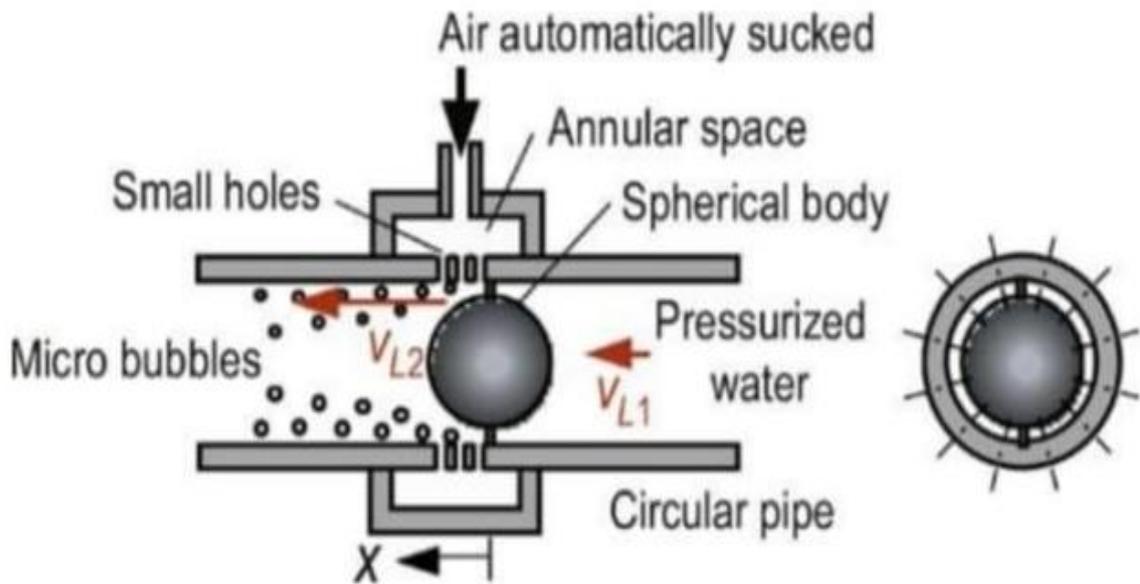


Figure (1-5) sadatomi MBG Model [29] .

## **1.4 Interface tension:**

To facilitate better understanding of studies involving a liquid-gas interface, knowledge of certain properties is necessary. One among them is the interfacial tension. Interfacial tension plays an important role in the stability of a colloid. Though interfacial tension and surface tension are used interchangeably, interfacial tension differs from surface tension in the fact that adhesive forces at the interface of the two fluids are the dominant factors in the former whereas cohesive forces between molecules of the same fluid are dominant in the latter. This also touches on the basics of single phase and two phase systems. Surface tension effect can be demonstrated by the meniscus formation on a water surface where the cohesive forces between the water molecules cause an inward 'pull' on the surface of the water. On the other hand interfacial tension in an air-water system can be visualized as a balance of forces at the interface of an air bubble in water. To attain a perfect balance, the cohesive forces of water molecules should be nullified by the internal pressure of the air bubble[40].

## **1.5 Flotation:**

It is the process of treating, separating and removing particles of low density from drinking water by using very small bubbles. Flotation can be used to remove materials of lower density such as algae or clay as an alternative to sedimentation. Based on the methods of generating bubbles, the flotation was classified as follows [40] :

1. electric flotation
2. dissolved air flotation (ADF)
3. dispersed air flotation.

Where the use of techniques such as electrostatic spraying and electric flotation is considered one of the best techniques for generating industrially microscopic bubbles inside the water surface due to the continuous operation of electricity. Oxygen bubbles form at the anode while Hydrogen bubbles form at the cathode, The diameters of the bubbles generated in this way range from 22 to 50 microns, depending on the experimental conditions, In the case of electrostatic spraying , several

electrically charged filaments act as an electrode and produce bubbles at the tip submerged in water [41]

The comparison between dissolved air floatation (conventional compressed atomization) with the two electrically stimulated methods of bubble size distribution reveals that electrostatic spraying has a wide distribution while pressurized atomization has a narrower distribution, i.e. the average bubble size is 40 microns, as in the following figure (1.6). The main reason behind the limits of the scattered volume is the application of high voltage during experimentation in order to reach a smaller bubble size and in such a case (high voltage), and when the corona is discharged at the end, bubbles are formed and the resulting final bubbles are of different sizes [40].

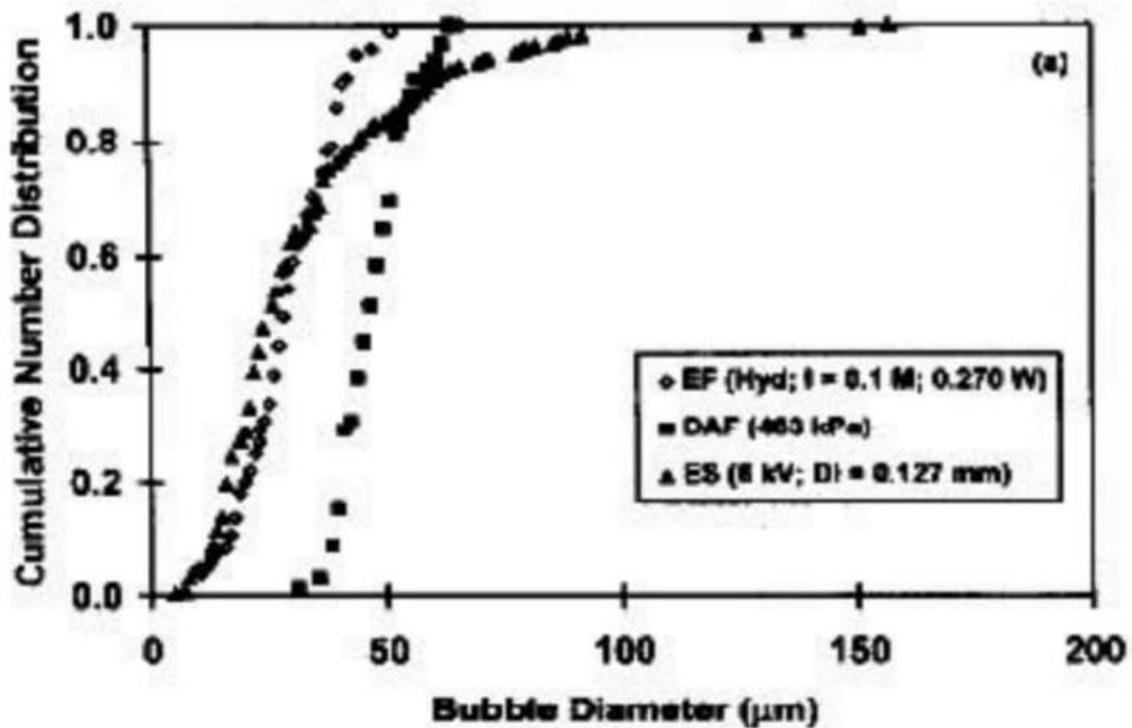
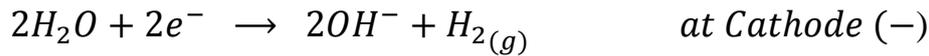
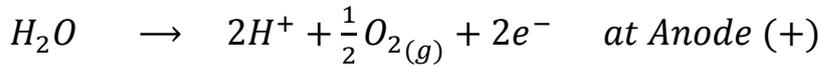


Figure (1-6) Distribution of bubbles size for the floatation process [42].

**1-6 Bubble diffusion :**

Plesset and Epstein used diffusion theory to calculate the life expectancy of infinitesimal air bubbles in water in a paper published in 1950. To diffuse to and from the bubble, the two driving forces are Laplace and gas-like pressure in water. The difference in pressure between the inside and outside of the gas bubble caused by surface tension and curvature of the surface is known as the Laplace pressure. When a force is produced parallel to the surface as a result of surface tension and its effect on stretching the surface, the surface bends around the bubble, resulting in a net force acting in the direction of the bubble. [40] ..

Also, the internal pressure creates an opposite force for the bubble, which leads to a balance of force from external pressure and surface tension. Laplace pressure is the internal pressure of the bubble is [41]:

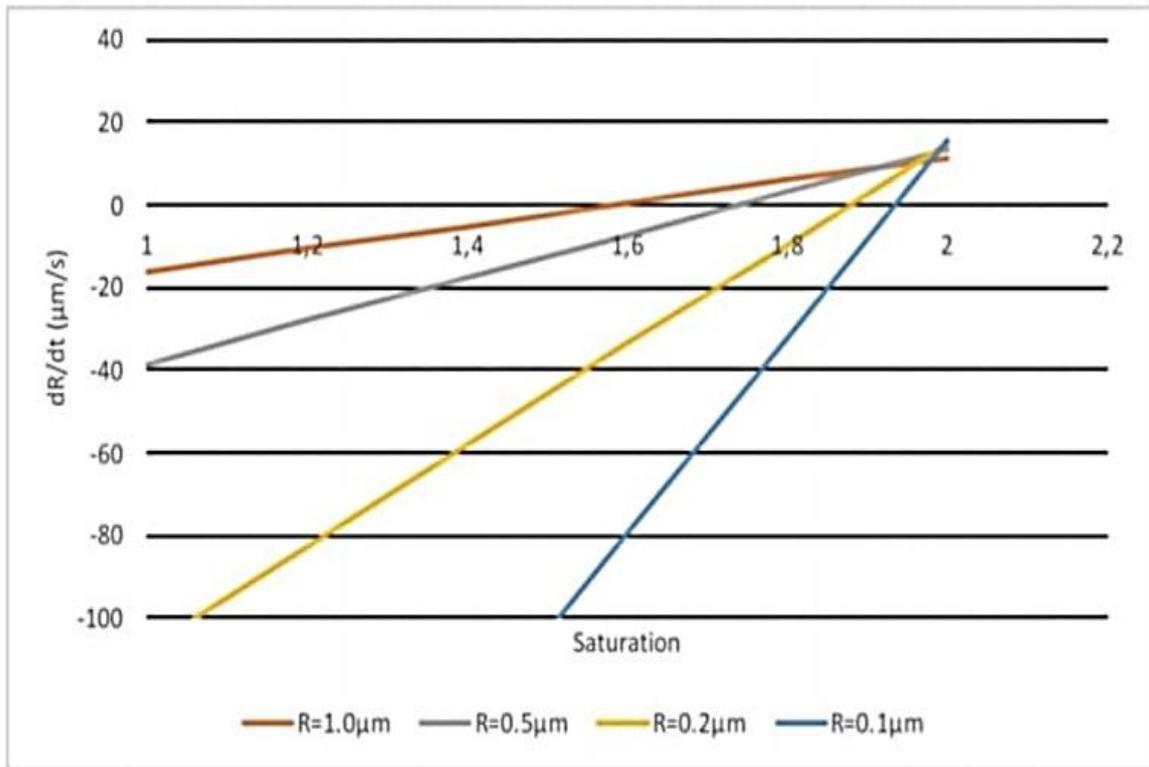
$$\Delta P = \gamma * \frac{2}{r} \dots \dots (1. 2)$$

where r is the radius,  $\gamma$  is the surface tension. When the surface tension is very high and the water-air interface is free of any absorbed surfactants, the bubble surface shrinks; otherwise, when there is no surface tension at the water-air interface, the bubble surface shrinks. Water is not polluted with air in this situation. If the water is saturated with air, the small bubble expands [41] .

However, the small gas bubble will have a very high Laplace pressure and it has a high surface tension (72 N / cm) which will cause the gas to disperse from the small bubble to the water even if it is in a moderately oversaturated state, as shown in Figure (1.7), to achieve A pure gas bubble of about 1 $\mu$ m, the Laplace pressure will be high to exceed (2.9 bar) and to push the dissolution with saturation greater than 150 percent, as in natural water, as shown in Figure (1.8) [44]. In their analysis, all of the plesset And Epstein made many simplifications, and others later developed more detailed models, but their predictions were confirmed experimentally with high accuracy ( $\pm 8\%$  for melting times) [45].

Plesset and Epstein believed that the bubble is stationary, that is, that movement through the liquid has no impact on the bubble. They also dismissed any convection induced by the movement of the interface due

to the shrinking of the bubble, and they believed that there were no other bubbles in the immediate vicinity that could prevent diffusion, instead relying on a single large bubble. Diffusion barrier at the interface, the air was supposed to circulate quite freely across the clean water and air interface, but not mentioned This assumption, clearly made by both Plesset and Epstein, has been taken for granted, and this may be important for the stability of the infinitesimal bubbles [46].



**Figure (1-7) Diffusion rate of change in radius (R) for a clean air bubble in water with a surface tension of 72N/cm and a temperature of 293K. [45].**

## **1-7 Literature Survey:**

### **1- M. Sadatomi, et. Al, (2004)[47]"**

A new micro-bubbles generator with a spherical body in a flowing water tube has been created.

In the engine, pressurized water is introduced into a pipe, and air is naturally sucked into the water stream.

Researchers discovered the ideal spherical body-to-pipe ratio.

The generator could generate microbubbles with a lower energy consumption rate of 40w, according to the diameter ratio.

### **2- Sung-Hocho, in (2005),[48]**

When aqueous solutions were sonicated with a palladium electrode, the robust nanobubbles had effective diameters of several hundred nanometers. The amicellar model was proposed to demonstrate the formation of nanobubbles and their size reduction. When salts were used, the bubble sizes grew marginally larger, but when surfactants were used, they shrank significantly.

### **3- Tomohiro Marui, in (2013) [49]"**

Micro-bubbles gradually shrink in size as internal gases are absorbed by the surrounding liquid.

Free radicals are created during the collapse of microbubbles, according to research

### **4- Palaniappan Arumugam, in (2015), [32]**

Water microbubble technology is well understood and widely used, but the fundamental mechanisms and characteristics of microbubble generation remain unknown. To enhance understanding, comprehensive literature analysis was combined with theoretical and experimental estimates of bubble size and measurements of volumetric mass transfer rate

**5-** Ziaeddin pourkarimi et, al, in (2016), [51]."

Fine bubbles have a major impact on gas hold-up, which is needed in mineral flotation. Using finer bubbles will help you save even more money.

Iran Mineral Processing Research Center has established an exclusive nanobubbles generation method. This unit, which improved Venture tubes, is functional.

**6-** Tsutomu Uchida, in (2016), [52]."

Micro- and nano bubbles O may be useful in industrial applications such as waste water purification and the promotion of physiological processes in living organisms. To develop such applications, we need to understand their properties and behavior, such as their lifetime and number density in solution.

**7-** Isaac Hung, in (2016),[53]. "

The aim of the, A project is to research the use of ultrafine bubble technology in conjunction with ozone gas for water treatment.

Water polluted with E was injected with ozone gas or nitrogen gas. Coli for up to 60 minutes as either ultrafine bubbles or fine bubbles as treatments. It was found that ultrafine bubbles had no major impact on the concentration of E. Coli in water. However, when used in combination with ozone, they did provide benefits that normal, fine bubbles did not.

**8-** Deendarlianto, et. al, in (2017), [54]

The search used a 30-degree inlet angle and a 20-degree porosity generator. As the demand for fresh water has increased, this has contributed to effective technologies efforts. The microbubble generator technology was recently developed to generate dissolved oxygen for waste water decomposition by breeding microorganisms.

**9-** Sangbeomkim, et. al, in (2018) [55]. "

The zeta potential of sub-micron (nano) bubbles decreases as pH rises, and this trend for micron bubbles remains constant. By irradiating them with ultrasonic waves, it may be possible to measure the concentration of

sub-micron (nano) bubbles by volume, allowing them to fuse into micron bubbles.

**10-** Muidh Hamed Alheshibri, in (2019) [56].

“Applications in various fields, such as water treatment and remediation, seed germination, surface cleaning, forth flotation and ultrasound imaging are stated to have. Bulk nanobubbles. To test if nanoparticle dispersions contain nanobubbles. It is important to develop methods. By their reaction to pressure application, these methods are demonstrated to be gas entities.

**11-** Bahaa h rabee, in (2020), [57].

"In order to create dissolved nano bubbles in water, high pressure and ultrasound are used. The highest strength of the dissolved nano bubble presence in water is (24 present) the project shows the ability of injecting ozone gas into water as ultrafine bubbles as a way to disinfect and treat water effectively and efficiently.

**1-7 The Aim of the Research:**

The performance of nano bubbles at the best hydraulic pressure and temperature in fresh water, in addition a new method for detection the existence of nanobubbles has been created.

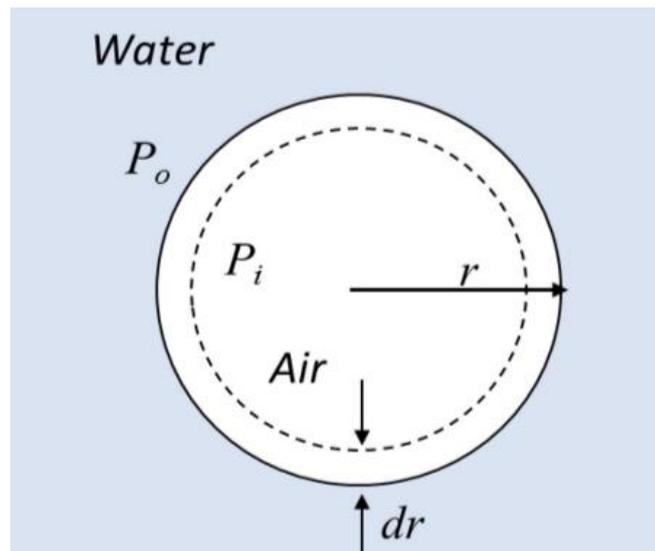
# ***Chapter Two***

## ***Theoretical Part***

## 2-1 Introduction:

In this chapter, the factors that affect nanobubbles are studied to provide basic information such as bubble size, concentration, growth and stability in water. Also the energy or pressure needed to overcome the effect of surface tension and the formation of nano bubbles. This energy cost is due to the intermolecular forces that hold the fluids together. Liquids with stronger intermolecular forces, this results in higher surface tension and lower surface tension of weaker forces, the greater the surface tension of the intermolecular forces, the greater the pressure needed to form a bubble. By reducing the surface area, the total surface energy of the bubble can be reduced, and thus small bubbles form into balls, as the sphere is the shape that has the smallest surface area for a given gas volume [59].

When bubbles form, they rise to the surface and burst. Likewise, the total surface area of the interface decreases. When two bubbles merge, the system energy decreases, In addition, the gas pressure inside the bubble contributes to reducing the volume, but a decrease in the surface area is achieved as the pressure inside increases as the bubble becomes smaller. The increase in pressure within the bubble is represented by the Young Laplace equation with respect to the immediate circumference[58].



**Figure( 2-1)**Schematic of an air bubble submerged in water. The bubble radius is  $r$ , the pressure outside the bubble is  $P_o$  and the pressure inside the bubble is  $P_i$ . A change in bubble radius  $dr$  will lead to a change in both volume and surface area [60].

Consider is a stable air bubble shaped with a radius of  $r$  in water Figure (2.1). An infinitesimal change in radius ( $dr$ ) leads to no change in free energy ( $dG$ ) at equilibrium. Let us now assume a slight decrease in radius  $dr$ . The system's surface energy would be diminished by the bubble's surface area decreasing. This is balanced during equilibrium by increasing the pressure within the bubble.

Described by the work done versus ( $\omega_p$ ) the pressure difference ( $\partial\omega_p$ ) [54]

$$\partial\omega_p = p dv \dots\dots (2.1)$$

Where  $P$  is pressure and the decrease in the occupancy corresponding to the inter facial area ( $\omega_s$ ) [55].

$$\partial\omega_s = \gamma dA \dots\dots (2.2)$$

$$dG = -\partial\omega_s + y\omega_p \dots\dots (2.3)$$

Where  $dG$  is the change of energy and  $\gamma$  is interfacial tension.

here is the surface area ( $A$ ) of the sphere ( $4\pi r^2$ ) and defines the change of surface area for a bubble shrinking by an infinitesimal ( $dr$ )

$$dA = 8\pi r dr \dots\dots\dots (2.4)$$

$$d\omega_s = 8\pi r dr \gamma \dots\dots\dots (2.5)$$

And since the work outside is equal to the work inside, but unlike the sign and from the geometry of the sphere we find.

$$\delta\omega_p = \Delta p 4\pi r^2 dr \dots\dots\dots (2.6)$$

And compensation eq (2.5) and eq (2.6) in eq (3.3) we find

$$dG = -8\pi r dr \gamma + \Delta p 4\pi r^2 dr \dots\dots\dots (2.7)$$

$$\frac{dG}{dr} = 0 \dots\dots\dots (2.8)$$

$$\Delta p = \frac{2\gamma}{r} \dots\dots\dots (2.9)$$

Equation (2.9) is the Laplace equation for a single spherical interface, it is the derivation of the Laplace equation of the sphere [61].

Where ( $\gamma$ ) is the interfacial tension for the bubble interface and ( $r$ ) is the radius of the nanobubble [62].

The pressure of Laplace shown in equation (2.9) is inversely proportional to the bubble size, and thus, the smaller the bubble, the greater the pressure. At nanobubbles, extremely high pressures are reached, For instance, in pure water with ( $r = 100$  nm), the corresponding internal pressure for nanobubbles is ( $\sim 1.5$  MPa). The pressure inside the bubble increases gas solubility, as described by the law of Henry, wherein the concentration of equilibrium,  $C$ , a fluid gas is proportional to pressure ( $p$ )[60].

$$C = K_h p \quad \dots\dots (2.10)$$

where  $K_h$  is Henry's law constant. If the amount of dissolved gas is equal to the equilibrium level of dissolved gas at temperature  $T$  and pressure  $P$ , a 100% saturation or "saturation" is obtained. "undersaturation" is obtained when the level of dissolved gas is below 100% and "oversaturation" is when it is above 100%.

100% The increase in solubility results in the diffusion from the bubble to the surrounding middle of gas molecules, thus reducing the radius of the bubble and increasing the pressure of Laplace further. The continuing process of dissolution thus amplifies the driving force for dissolution and contributes to the disappearance of bubbles. However, when the solution is supersaturated with dissolved gas, a different scenario is predicted [59].

If the gas concentration within the solution is sufficiently high, the gas diffusion direction will be reversed. Gas moves into the bubble in this case, causing it to grow, this will decrease the pressure of Laplace and thus decrease the solubility of the gas in the solution surrounding the bubble gas will begin to expand into the bubble resulting in an increase in the size of the bubble, thus decreasing the pressure of Laplace and the solubility of the gas in the solution surrounding the bubble

As a consequence, due to the increase in buoyancy, the bubble will expand rapidly and rise to the surface and then burst and disappear [58].

it is possible to calculate the bubble's internal pressure. . ).

$$P_g = P_L + \frac{2\gamma}{r} \dots\dots\dots (2. 11)$$

Where ( $P_g$  and  $P_L$  ) are the gas and liquid pressure respectively (Pa),  $r$  is the bubble radius(m) and the ,  $\gamma$  ( $N.m^{-1}$ ) is interfacial tension) [82].

Note that the difference in pressure between liquid and gas is inversely proportionate to the radius of the bubbles. The large bubbles with a diameter in 1mm, For example, has an internal pressure of (0.102  $\mu$ pa) , while a small bubble with a diameter of 10 $\mu$ m) has an internal the pressure of (0.130MPa) using Eq. (2-11). According to Henry law, because of the high pressure of the gas within, breakdown of gas in the liquid increases[78].

$$C_i = k_h P_i \dots\dots\dots (2. 12)$$

Where  $C_i$  is the molarity of the (i) species dissolved in saturation state in the liquid ( $mol.m^{-3}$ ),  $k_h$  is the Henry law constant ( $mol.m^{-3}.Pa^{-1}$ ) and  $P_i$  is the gas phase partial pressure of the (i) specie ( $\mu$ Pa) , described by[78]

$$C_i = X_i P_i \dots\dots\dots (2. 13)$$

$X_i$  is the molar fraction of (i), the bubble begins to shrink with the rise in the dissolution of gas into liquid, microbubbles, therefore, have a higher shrinking rate the macrobubbles.

It was found by the voltage calculation that the surface of microscopic bubbles was negatively charged in large range of pH [77].

In gas - water interface charging mechanism, the also stressed the value of  $H^+$  ions and  $OH^-$ . With collapse in the microscopic bubbles in the absence of dynamic stimuli, the production of free radicals has been observed [79]. And it is also possible to estimate the stagnation of the bubble in water from the final velocity , according to Strok's Law [80].

$$v = \frac{1}{18} \frac{(\rho_g - \rho_L)gd^2}{V_s} \dots\dots\dots (2. 14)$$

Where ( $v$ ) is the final velocity ( $m.s^{-1}$ )  $\rho_L$  and  $\rho_g$  (are the densities of the liquid and gas respectively ( $Kg.m^{-3}$ ),  $g$  is the gravity ( $m.s^{-2}$ ),  $d$  is the diameter of the bubble (m). and  $V_s$  is the viscosity of the surrounding fluid (Pascal.sec).

For example, if we take a 100 nm diameter bubble with a final velocity ( $v$ ) of ( $6 \times 10^{-5} mm.s^{-1}$ ), while a microbubble (100  $\mu m$ ) diameter will grow at  $6 mm.s^{-1}$  and a macrobubble of 1 mm

Diameter will increase rapidly of around  $600 mm.s^{-1}$  (using  $\rho_g = 1.184 Kg.m^{-3}$  and  $\rho_L = 997 Kg.m^{-3}$  appropriate to the air and water densities at 25 °C , respective;  $g = 9.8 m.s^{-2}$ ,  $V_s = 8.99 \cdot 10^{-4} Pa.s$ , appropriate to the water viscosity at (25)°C

The specific of area ( $a_v$ ) is determined by the surface area ratio to each volume, and the given area in the case of a spherical bubble with a diameter of  $d$ , specified area is [80] :

$$a_v = \frac{\pi d^2}{(\pi d^3)/6} = \frac{6}{d} \dots\dots\dots (2. 15)$$

This reduction in the diameter of the bubble results in a particular region that is large.

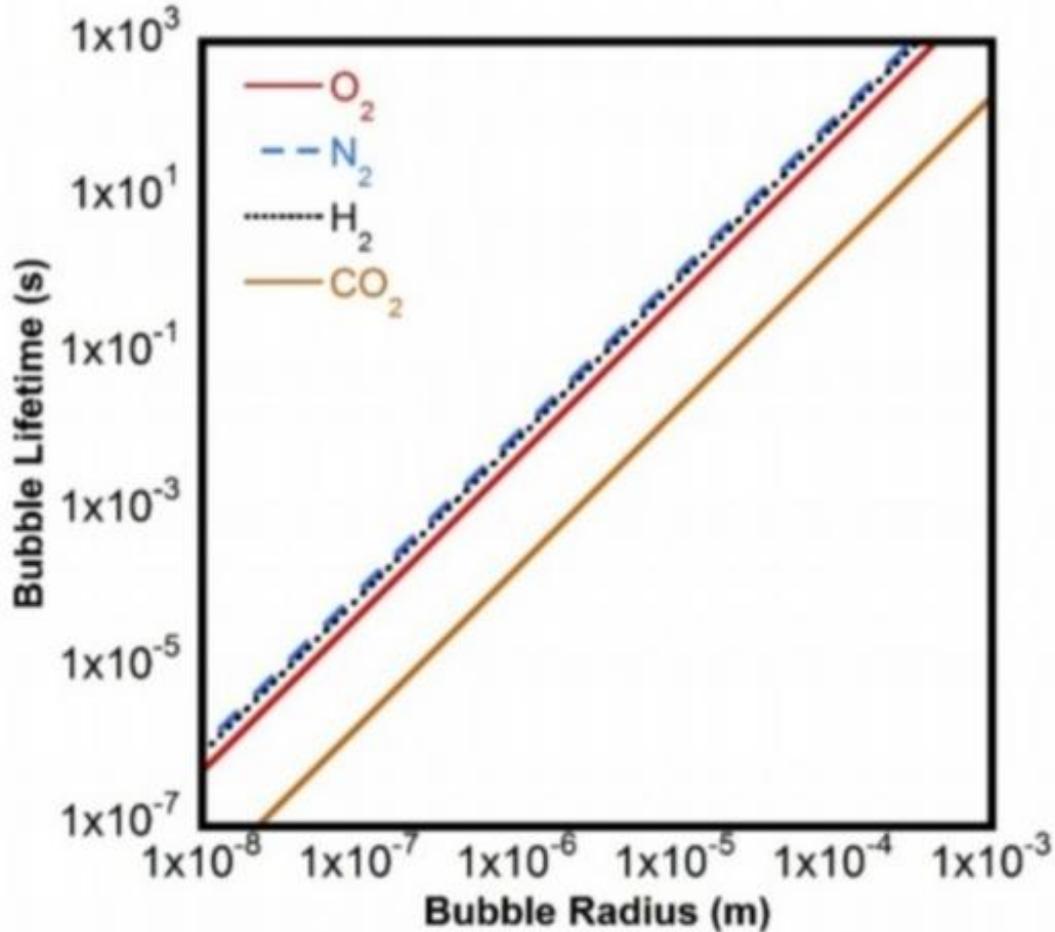
**2.2 The lifetime of bubbles**

In 1997, Ljunggren and Eriksson created a theory to precisely measure the lifetime of bulk nanobubbles. In direct response to evidence of the presence of surface nanobubbles, this work was published. Their estimation was consistent with the theory of Epstein and Plesset, and they claimed that "bubbles of colloidal size have a limited lifetime in water, " In equation (2.16), their expression or lifetime is given for a bubble with an initial radius  $r_o$ , the Ljunggren and Eriksson model are equation [63]

$$t = \frac{k_h r_o^2}{3RTD} \dots\dots\dots (2.16)$$

Where  $t$  is the lifetime of the bubble,  $K_h$  is Henry's law constant,  $R$  is the ideal gas constant,  $T$  is the temperature, and  $D$  is the diffusion constant.

As a function of its original radius, Figure( 2-2) shows the predicted lifetime for a gas bubble? Using a model from Ljunggren and Eriksson Equation (2.16), It is clearly seen that a nanobubble like this can dissolve very easily. The effect of the gas form on the lifetime of gas bubbles is also taken into account in the calculation in Figure( 2-2), where a gas with higher solubility (e.g. CO<sub>2</sub>) dissolves more rapidly than a gas with lower solubility (e.g. O<sub>2</sub>, N<sub>2</sub>, or H<sub>2</sub>)[63].



Figure( 2-2) Expected lifetime for a bubble in water as a function of the initial radius and gas type using the Ljunggren and Eriksson model (equation 2-16)[59]. The parameters used in this calculation are  $K_H(O_2) = 7.7 \times 10^4 \text{ J mole}^{-1}$ ,  $K_H(N_2) = 15.6 \times 10^4 \text{ J mole}^{-1}$ ,  $K_H(H_2) = 13 \times 10^4 \text{ J mole}^{-1}$ ,  $K_H(CO_2) = 0.3 \times 10^4 \text{ J mole}^{-1}$ ,  $D = 2.0 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ ,  $T = 298 \text{ K}$ . [68]

The results of Epstein and Plesset and Ljunggren and Eriksson had a profound effect on the study of nanobubbles, as it contributed to reports of long-lived nanobubbles being regarded with great caution and dubiousness. [67].

### 2-3 Zeta potential:

The potential difference between the fixed layer of water and the dispersion medium is referred to as the zeta potential [33]. Where the values of the zeta potential are expressed as a numerical description of the stability of the loop solution or dispersion, It is widely incorporated into emulsion systems and is described as the potential difference between the water stationary layer connected to the dispersion object and the dispersion medium. It can be concluded that the repulsive forces between the dispersed media control the attraction forces as the potential of the zeta potential increases and also prevent its accumulation in the form of froth and sintering [35]. The microscopic bubbles also showed a potential range of zeta potentials associated primarily with negative values. The close relationship between pH and zeta potential was validated. And by using the pH values of the solution with the addition of different surfactants, Ionic concentrations are related to negative values. Detailed research on potential differences is a Zeta system of microscopic bubbles in air and water that has been tested by different techniques with varying experimental conditions in the literature [35].

$$\mu = \frac{\varepsilon_0 \varepsilon_w \zeta}{V_s} \dots\dots\dots (2.17)$$

Where:

$\mu$  is the mobility ( $10^{-8} m^2 S^{-1} V^{-1}$ ),

$\varepsilon_0$  is the permittivity of free space ( $Coulomb(C^2).Jules(J^{-1}).mater(m^{-1})$ ),

$\varepsilon_w$  is the relative permittivity of water, and

$V_s$  is the Viscosity of water ( $g cm^{-1} s^{-1}$ )

$\zeta$  is the Zeta-Potential (mV) . The half width at half height of Zeta-Potential was less 15mV in all the cases .

The higher the negative Zeta Potential, the smaller the radius of the nanobubbles.

## 2-4 Bubble growth and shrinkage:

Each bubble is defined by a radius ( $r_c$ ), which is as given by the Young Laplace equation, which has been simplified. Where bubbles larger than  $r_c$  tend to increase in size and vice versa where bubbles smaller than  $R$  tend to have a decrease in volume. The radius of the newly designed bubble becomes greater than the critical radius ( $r_c$ ) when bubbles merge or bubbles combine, and internal diffusion of gas occurs when the bubble begins to expand and becomes a large bubble. Since microscopic bubbles have a very low velocity, this increases the time for a small bubble to stay in the appropriate liquid or water. A case of a micro-bubble system in (water, air) that develops the phenomenon of slow rise in velocity of micro-bubbles and surface contraction has been recorded [40]. With the diminution of the micro-bubble size, a plot of the zeta potential of the micro-bubble appears on the shrinkage scale for the negative value of the zeta potential of the micro-bubble. During their ascent, the effect of the buoyancy force on microscopic bubbles initiates minute levels of bubble diffusion and initiation of their shrinkage. In contrast to the central bubbles and milli bubbles that rise to the surface of the water and burst, while the microscopic bubble collapses beneath it and from this phenomenon, the generation of free radicals in the water was determined and also the shrinkage gradually over time, as in Figure (2.3). What makes free radicals highly reactive is that they contain unpaired valence electrons [27]. However, generating free radicals requires a dynamic stimulus such as cavitation or ultrasound. Micro-bubbles, which generate free radicals, are thought to have a combined effect on the shrinkage process, along with negative values of the high Zeta potential, as shown in Figure (2.4). Increase the ion concentration on the bubble's surface as well [27].

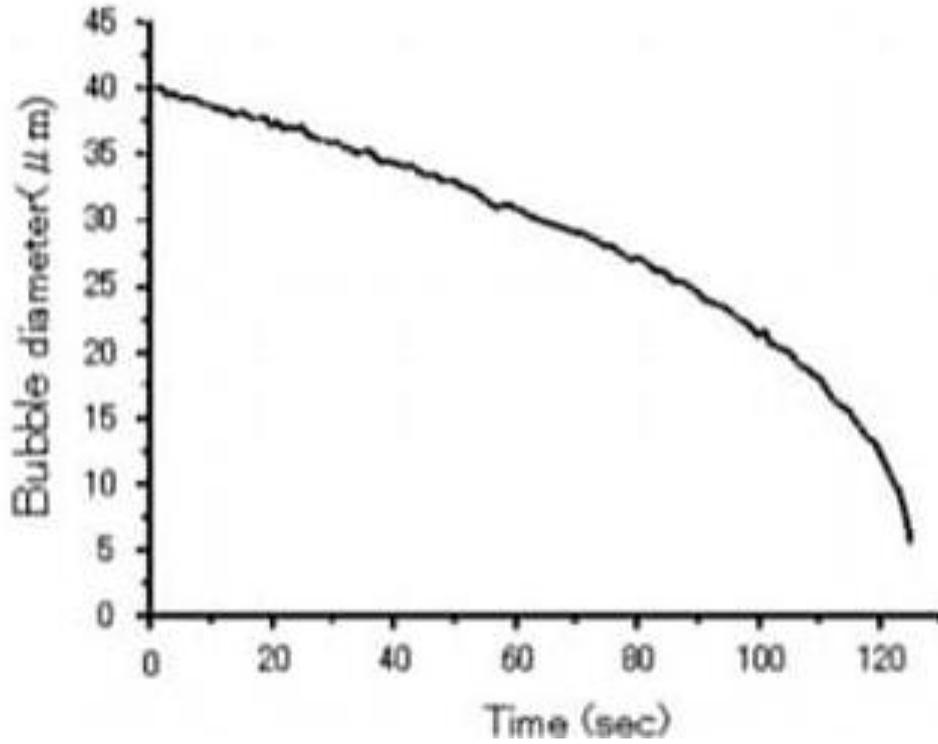


Figure (2-3) Bubble Shrinkage [27].

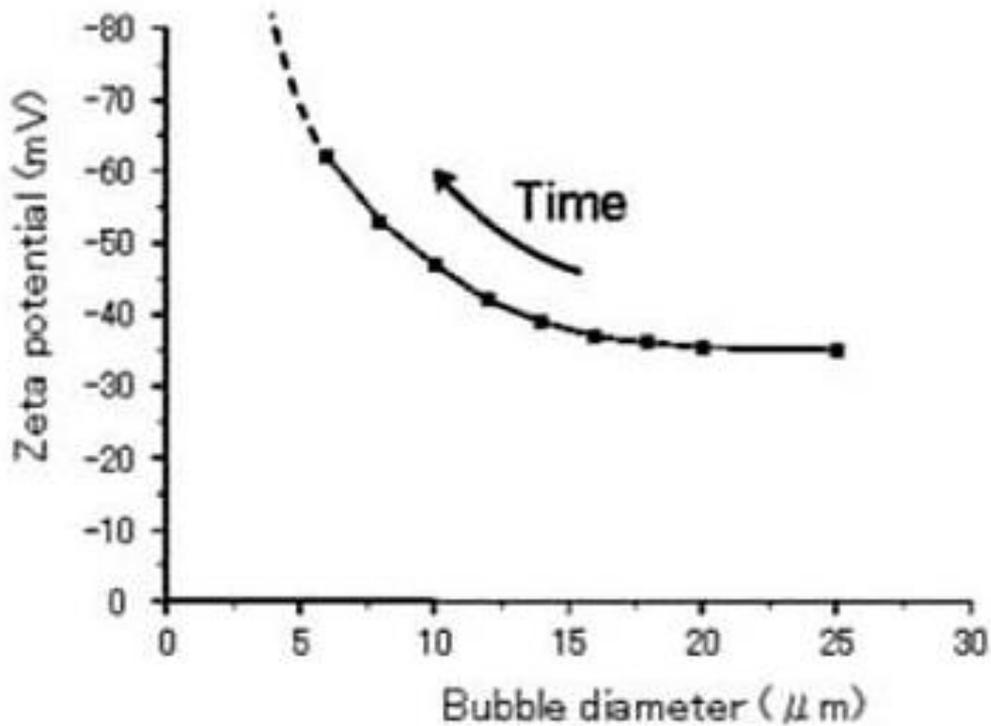


Figure (2-4) Zeta Potential Variation [27].

## **2-5 Ozone from Micro-bubbles:**

Since it attaches to the cell walls of bacteria and stabilizes them, ozone is one of the most common and efficient disinfectants associated with water technology. Ozone treatment units are built in almost every commercial water treatment facility, but ozone using micro-bubble technology is uncommon at the moment. Research interests continue to be the production of fine ozone bubbles for a variety of applications. Ozone is sparingly soluble in water, however the ozone diffuse into the water was not as reliable and successful as it was assumed that resulted from limitations such as low mass transfer rates. The unused quantities of ozone trapped inside the water[44]. The mixing properties of the liquid and gas conductor and the process of ozone decomposition inside the water, along with the density and size of the bubble are important factors that affect the solubility of ozone in water [41]. The micro-ozone process for water was performed using a patented commercial bubble generator to investigate the effect on sludge dissolution and compare it with the bubble conductor [45]. In addition to a multifaceted increase in total and soluble chemical oxygen demands (SCOD), a bubble conductor was used to achieve an 80 percent inactivation of microorganisms with a minimum inactivation of 50 percent. Reports have been published on the efficient removal of different strains of bacteria and comprehensive practices in the food processing sector[47]. A new design that integrates an oscillating air lift technology into the bioreactor system to effectively create ozone bubbles with high mass transfer rates was recently established by . The electrostatic ozone reactor was developed at high voltage levels [48]. And assessed the ozone mass reduction, and due to poor system control and pressure fluctuations the results failed to agree [41] as in the figure (2-5).

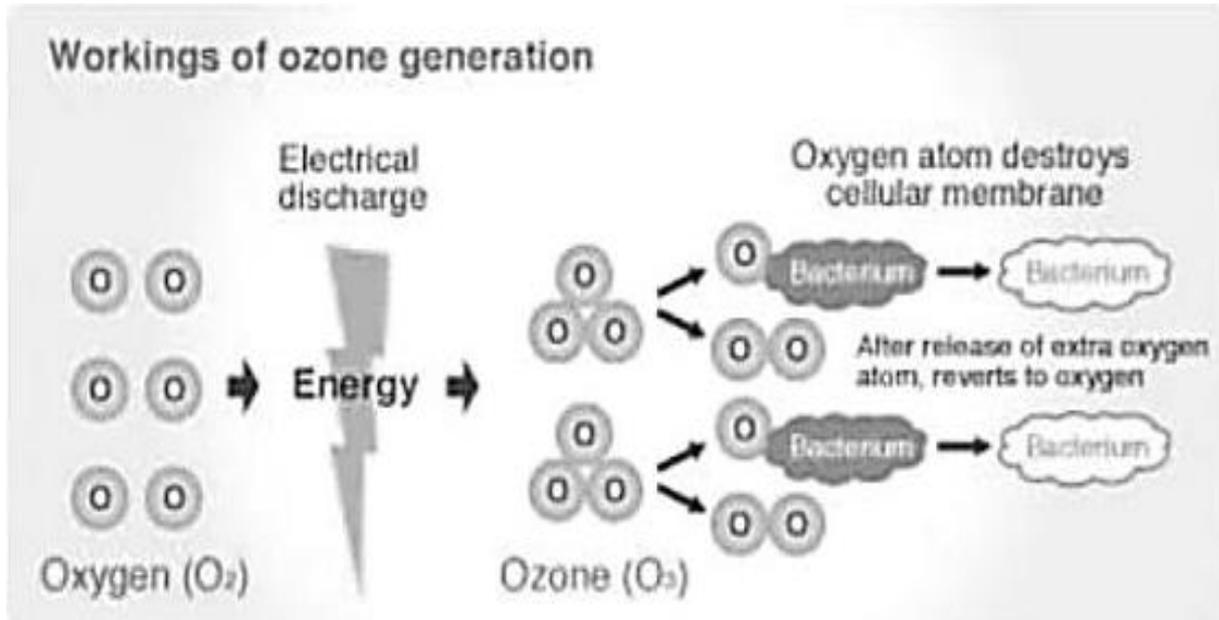


Figure (2-5) Mechanism of Ozone generation[41].

## 2-6 Dissolved oxygen in water

A measurement of dissolved oxygen (D.O) was performed in addition to the bubble size prediction. The amount of dissolved oxygen in water (D. O) is measured in milligrams per liter (mg/L) or percentage saturation. %

$$\text{saturation} = \left( \frac{D.O}{\text{Saturation Level}} \times 100 \right) \dots\dots\dots (2.18)$$

Concentration, temperature, and altitude indicate that the colder the water, the greater its capacity for gas (D.O) retention. In the aquaculture sector, (D.O) levels are of paramount importance [49], because plants and animals that reproduce in water need oxygen to survive..One of the most relevant and most common examples is the monitoring and monitoring of (D.O) levels. . D. O levels in aquariums and fish ponds D.O. was calibrated using an Exstik D.O. 600 meter (with temperature sensor) capable of reading values up to 25 mg/L for our experiments. The effect of pressure on D. O is shown in Fig. (2.6). It is observed that it has a direct linear relationship.[49].

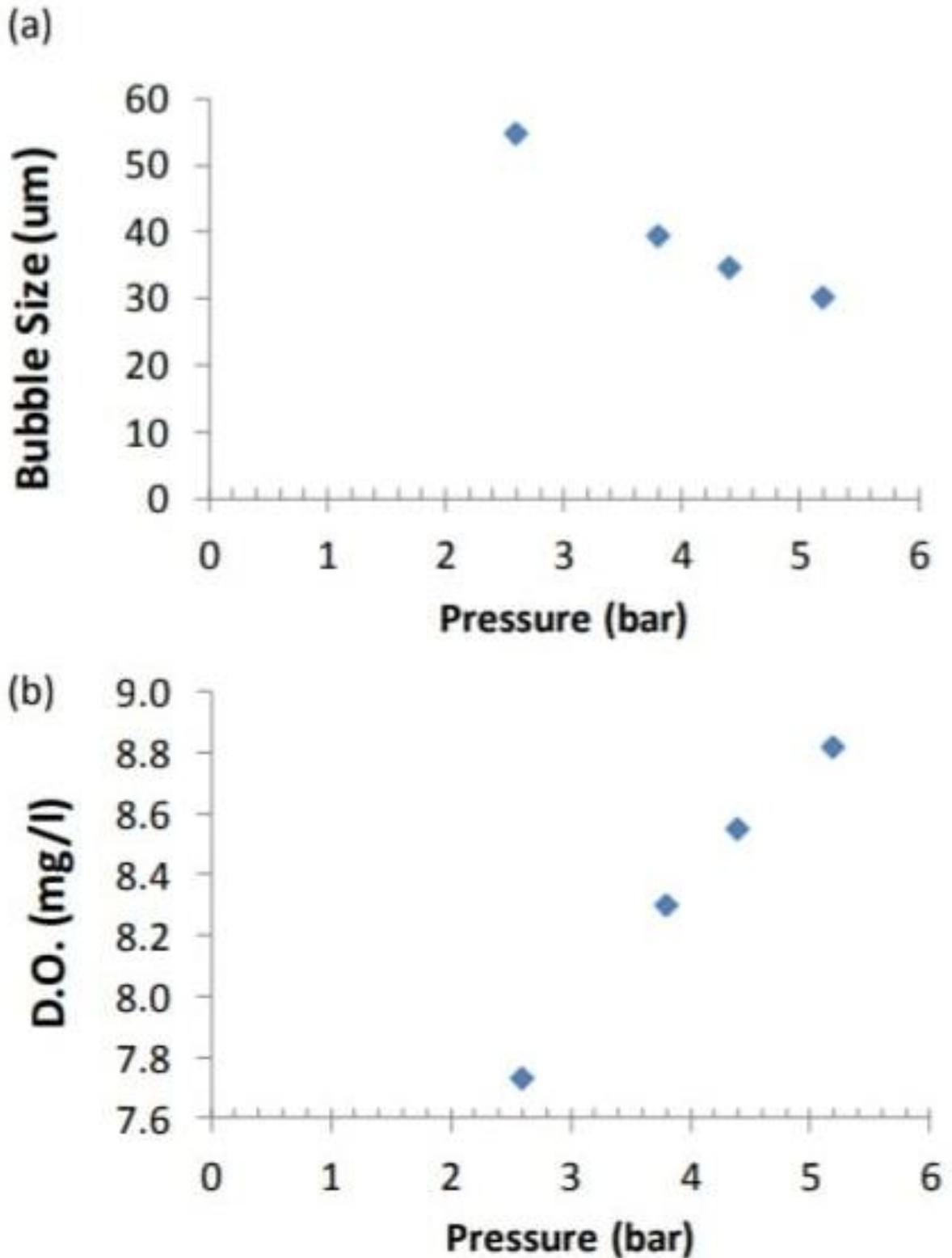


Figure (2-6) Effect of Pressure on a: bubble zise, b: D.O. levels [49]

Confirming the effectiveness of microscopic bubbles in influencing the levels of D. O, a comparative analysis was performed. As shown below, a clear comparison between an air stone or (aggregate) that

produces milli-bubbles of tens of millimeter order and MBG. For the same gas flow velocities, the comparison evaluates the performance of microscopic bubbles over large bubbles. Figure (2.7A) shows the group of air stones before and after ventilation, while Figure (2.7B) shows MBG before and after ventilation.

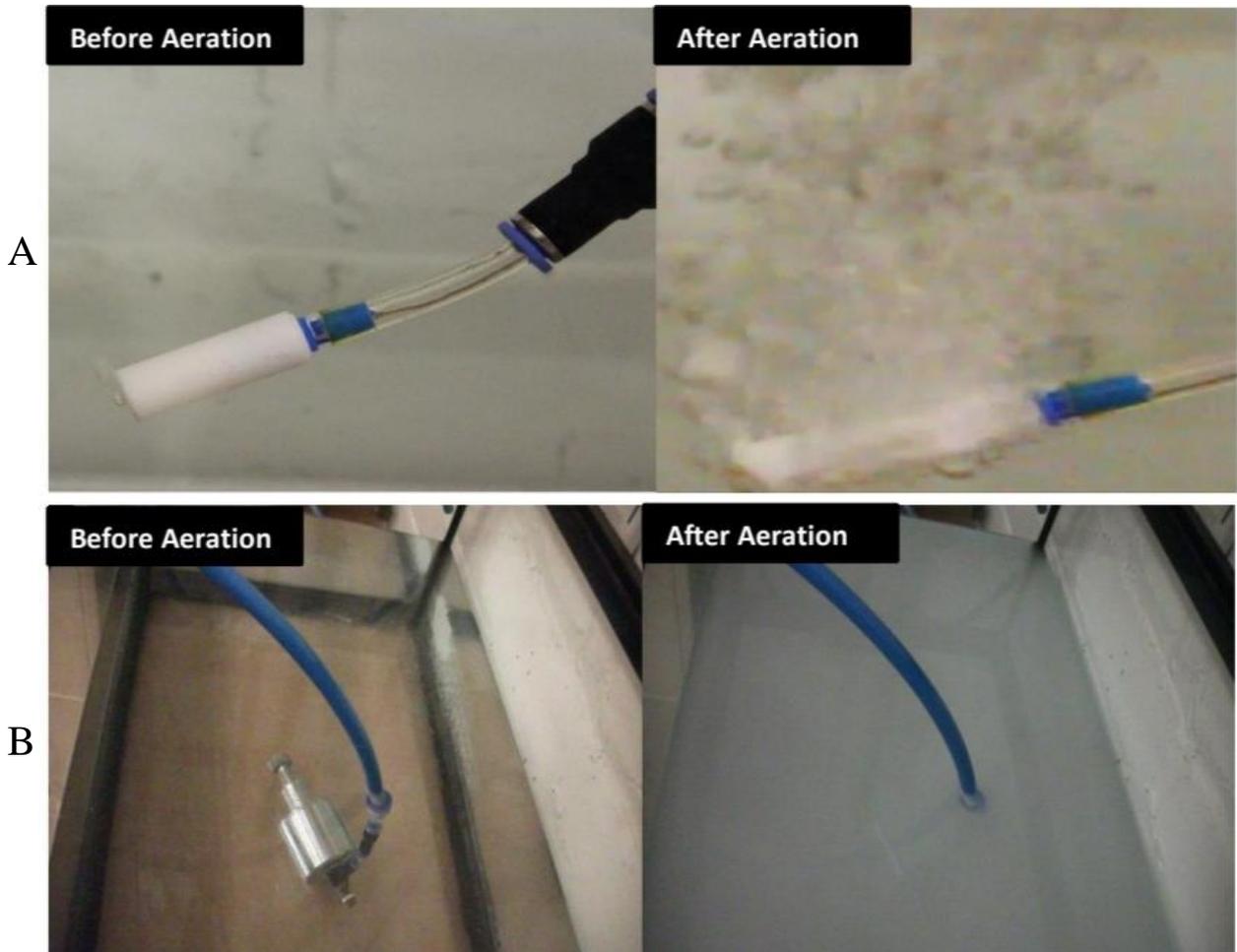


Figure (2-7A) Micro Bubble Generator\_Air Stone (top),[49],

Figure (2-7B) Microbubble generator (bottom )

### 2-7 Longer microbubbles residence time:

The primary significance of micro gas bubbles inside water is their extremely slow rising velocity. Microbubbles shaped on the surface of water have a different growth and collapse mechanism than macrobubbles (which vary in size from millimeters to several centimeters) .

As shown in Fig. (2.8), The participation of bubble size and velocity increase in direct proportionality calculated by the velocity equation for Stokes law is shown in a graphical comparison of velocity

increase for different sizes of bubbles. According to Stokes' law, the increased velocity is given by[43]:

$$v = \left(\frac{1}{16}\right) * (\rho_g - \rho_L) * g * d^2 / V_s \dots\dots\dots (2.19)$$

If  $\rho_L$  is the liquid density,  $\rho_g$  is the gas density,  $g$  is the gravity acceleration,  $d$  is the equivalent bubble diameter, and  $V_s$  is the liquid dynamic viscosity. The formulation, however, is defined by assumptions that consider each bubble during its ascension to be an isolated sphere devoid of collisions and coalescence. In the theoretical and experimental rising velocities, conformal similarity was observed.

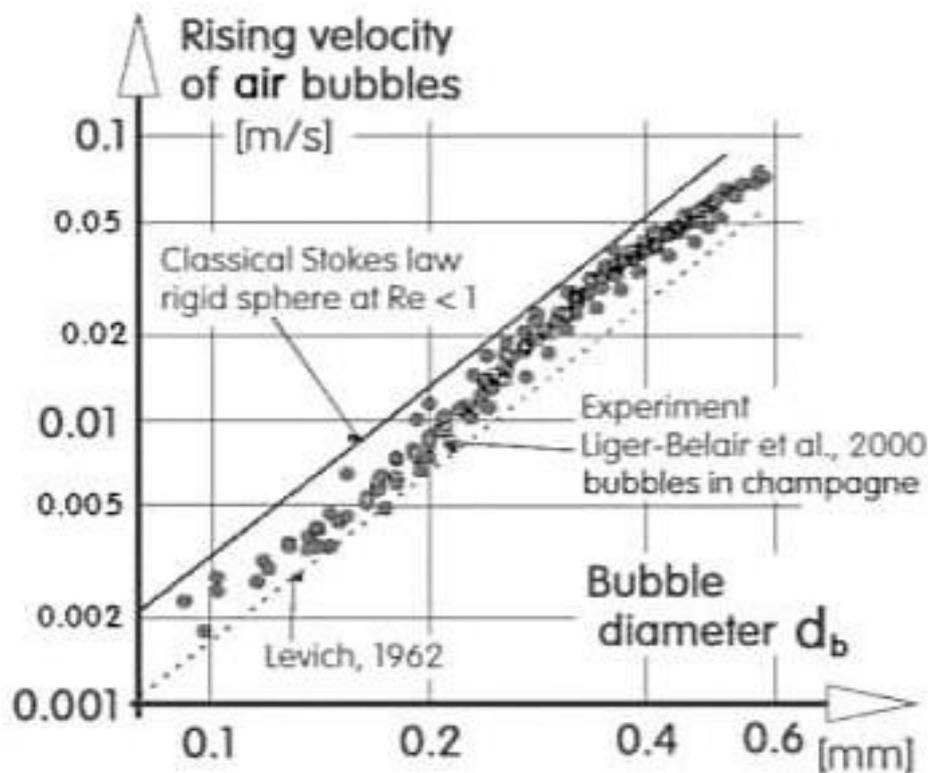


Figure (2-8) The speed at which a bubble rises [43]

The low speed can also be explained in terms of two types of forces: the long-range body force ( $F_b$ ) and the short-range surface force ( $F_s$ ) [64].

$$F_b = (\rho_{water} - \rho_{air}) * Volume = (\rho_{water} - \rho_{air}) * 4/3 * \pi * r^2 \dots\dots\dots (2.20)$$

$$F_s = K_h * Surface Area = 4 \pi r^2 K \dots\dots\dots (2.21)$$

$$F_{axial} = F_s + /-F_b / = F_s(1 + /-F_b/F_s) \quad (2.22)$$

Submitted equation (2.20)&(2.21) yeild F axial:

$$F_{axial} = 4 \pi r^2 (K + /-(\rho_{water} - \rho_{air}) / * 1/3 \quad (2.23)$$

The term  $1/3(\rho_{water} - \rho_{air}) /$  loses significance as r decreases, therefore, Eq. (2.23) is reduced to:

$$F_{axial} \approx F_s = K * 4\pi K r^2 \quad \dots\dots\dots (2.24)$$

As the bubbles decrease in size, their volumes decrease and the body force magnitude decreases relative to the surface force-a low body force means a low speed rise. Although the local surface force decreases, due to the expanded surface area, the total surface force appears to be strong, and thus, the surface force plays the predominant role and effects the change in increasing velocity [64].

**2-8 Theoretically measuring the size of the bubble:**

Using basic experimental measurements, the size of the bubble was predicted in theory. The microscopic bubbles give the water a milky white color. The theoretical calculations of the bubble volume were performed on the basis of the observed clearance time after aeration for a limited time period. Then post-purging was performed for 10 min and mean values were calculated. To predict the diameter of a small air bubble in water, all known values fit into the Stoke equation. The following are the assumptions made in this calculation[85]:

1. A small bubble is a ball free of irregularities, i.e. perfect shape.
2. The same upward trend follows each bubble.
3. There is no fusion, and its effect on the mean overall diameter is marginal if any.
3. Unidirectional elevation velocity along the coordinate path.

Stock's equation[85]

$$\text{Rising Velocity } v = \frac{1}{18} * (\rho * g * d^2) / V_s \quad \dots\dots\dots (2.25)$$

Hadamard Rybczynski equation: Rising Velocity[85]

$$v = \left(\frac{1}{12}\right) * \frac{\rho * g * d^2}{V_s} \dots\dots\dots (2.26)$$

Stock's equation differs from the latter by a constant of 18/12, which equals 1.5. stock's equation will be used in future for the sake of simplicity [85].

**2-9 Interfacial area:**

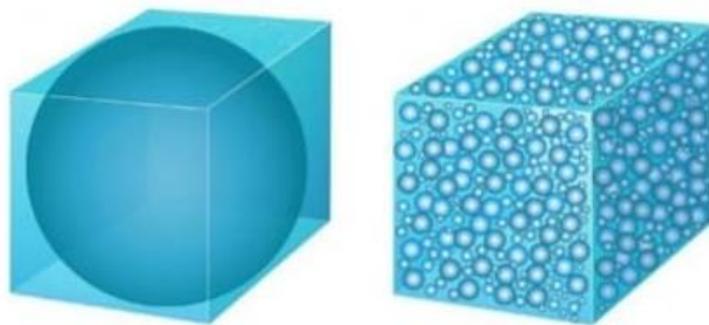
The increase in available surface area of micro-bubbles for the same macro-bubble volume is significant, and it can be seen by calculating the surface area to volume ratio of the perfect sphere as follows: (assume each bubble is round sphere)

$$Surface\ area = 4 * \pi * r^2 \dots\dots\dots (2.27)$$

$$V = \frac{4}{3} \pi r^3 \dots\dots\dots (2.28)$$

$$Surface\ area: Volume = \frac{3}{r} \dots\dots\dots (2.29)$$

This relationship emphasize the fact that as the bubbles get smaller, more surface area becomes available for the same amount, as seen in Figure (2.9). This promotes mass transfer sites, and froth flotation is classic example of how this property of micro and nanobubbles is put to good use [66].



**Figure (2-9) Macro and Micro Bubbles.**

## 2-10 Stability:

The Young-Laplace Stability Equation (Equation 2.11) is used to describe the internal pressure of macro- and microscopic bubbles. The question is if there is a radius limit for this equation's validity. For example, a 100 nm radius bubble will have an internal water pressure of 1.5 MPa (using  $\gamma = 0.072785 \text{ Nm}^{-1}$ , [66]) on a nano-scale, which is so large that it is unlikely to be stable at atmospheric pressure. Therefore, nano-bubbles should have a very short length.

Bubbles with radii of 10 and 100 nm would have lifetimes of 1 and 100 s, respectively, as discovered in accordance with this hypothesis. The calculations were based on the diffusion of dissolved gas molecules from a spherical gas bubble to determine the shrinkage rate. The Young - Laplace Equation was used in the calculation [68].

$$p_g = p_L + 2r \quad \dots\dots\dots (2.30)$$

and Henry's Law

$$C_i = K_h P_i \quad \dots\dots\dots (2.31)$$

On the other hand [69] stated that for nano bubbles, equation (2.11) is not applicable. Using simulation of molecular dynamics, the authors concluded that within the nano-bubble there are too few vapor atoms, which was unable to maintain a high enough pressure to maintain the force balance with the outer side. The liquid- vapor interface would play an important role in maintaining a nano- force bubble's balance in this case, and the nano-bubble would be stable at low levels as a result. In addition to the conflicting evidence showing that there is no consensus on the nature and stability of the nano-bubbles, realistic knowledge for understanding these issues is still missing in the literature. The experimental detection of nano-bubbles and a thorough analysis of their stability are therefore required.

According to [70], the surface tension is greatly affected by the curvature of the interface and maintains the internal gas in that dimension, so equation (2.11) might not be applicable to very small bubbles. The surface tension of droplets was measured theoretically, and it was concluded that the surface tension would decrease significantly for small drops [71]. The surface tension varies with the curvature of the gas-

liquid interface. As a result, the internal pressure of a very small bubble should be different in magnitude

### 2-11 Brownian motion:

Very small particles in a gas or liquid move randomly, and this movement is called in the name of the scientist Robert Brown the Brownian motion, who studied phenomena on a massive and extensive scale [77]. In 1905, Albert Einstein published a historical paper in which he explained theoretically how they collide at random. For particles small enough, the particle and the particles of the surrounding medium may be irregular, causing the particle to travel in random directions. The particles in the surrounding medium move faster at higher temperatures which makes the movement stronger, and allows the medium to move faster, where the equation is The particle diffusion or the diffusion (D) is[77]:

$$D = \frac{k_B T}{6\pi V_s r} \dots\dots\dots (2.32)$$

where  $k_B$  is Boltzmann's constant, T the absolute temperature.  $V_s$  the viscosity of the liquid and r the hydrodynamic radius of a spherical particle. The Stokes - Einstein relation is the name given to this formula. Surprisingly, the diffusivity of a particle is unaffected by its mass. D can be thought of as a measure of the Brownian particle's positional fluctuation. As the temperature rises, the random movement of the Brownian particle increases, reducing the residence time of bubbles dissolved in the water .

### 2-12 Optical properties:

The changes in electronic properties with size result in major changes in the optical properties of nanosized materials [67]. If particles are made small enough, quantum effects come into play, which limit the energies at which electrons and holes can exist in the particles, as energy is related to wavelength, this means that the optical properties of the particle can be finely tuned depending on its size[83]. Thus, particles can be made to emit or absorb specific wavelengths of light, merely by controlling their size[72]. Knowing the spectrums of absorption and transmittance nano materials assist in identifying many optical properties in different ranges of wavelengths[84]. Conducting examination at the ultraviolet spectrum

range enables us to know the type of the bonds, orbital and energy beams[50] .This is provided with information about the nature of the change constants such as absorption coefficient, refractive index, reflectivity [73]

**2-12-1 Absorbance (A)**

Absorbance is defined as negative common logarithm of transmittance (T) and or the logarithm of the ratio between absorbed light intensity ( $I_A$ ) by material and the incident intensity of light ( $I_o$ ) of a sample [74, 38]:

$$A = - \log IA/I_o = \log(I_o / IA) \dots\dots\dots (2.33)$$

**2-12-2 Transmittance ( $T_o$ )**

Transmittance ( $T_o$ ) is given by reference to the intensity of the rays transmitting from the surface (I) to the intensity of the non it ( $T = I/I_o$ ), and can be calculated by [75] :

$$T_o = \exp (-2.303A) \dots\dots\dots (2.34)$$

**2-12-3 Reflectance (R)**

It's given by ratio of the intensity of the rays ( $I$ ) reflecting of the film to the intensity of the incident rays ( $I_o$ ) as follows :

$$R = I_T / I_o \dots\dots\dots (2.35)$$

and reflectivity can be obtained from absorption and transmission in accordance to the law of conservation of energy as relation [76]

$$R_o + T + A = 1 \dots\dots\dots (2.36)$$

# ***Chapter Three***

## ***Materials and Methods***

**3-1 Introduction:**

In this chapter, the method used to create nano-bubbles is described. And the use of a device to measure the amount of dissolved air in water (chemical correction). Also describe the spectrometer device used to measure the reflectivity and absorbance.

**3-2 Materials used:**

The materials used in this study are pure water only, without any additives, and at room temperature. Devices for converting large bubbles into micro bubbles and microscopic bubbles were used by a water pump that uses reverse fans at a speed of 1500 cycle /min, as it begins to break down large bubbles and break them into micro bubbles.

Which are locally made in the Al-Ithmar Agricultural Company in Alexandria It contains eight spiral channels operating in a twirl way, and the water mixed with bubbles enters another stage in the same cylinder that contains multiple fans totaling fifteen fans, and its mission is to generate the largest number of micro and nano bubbles through multiple collisions.

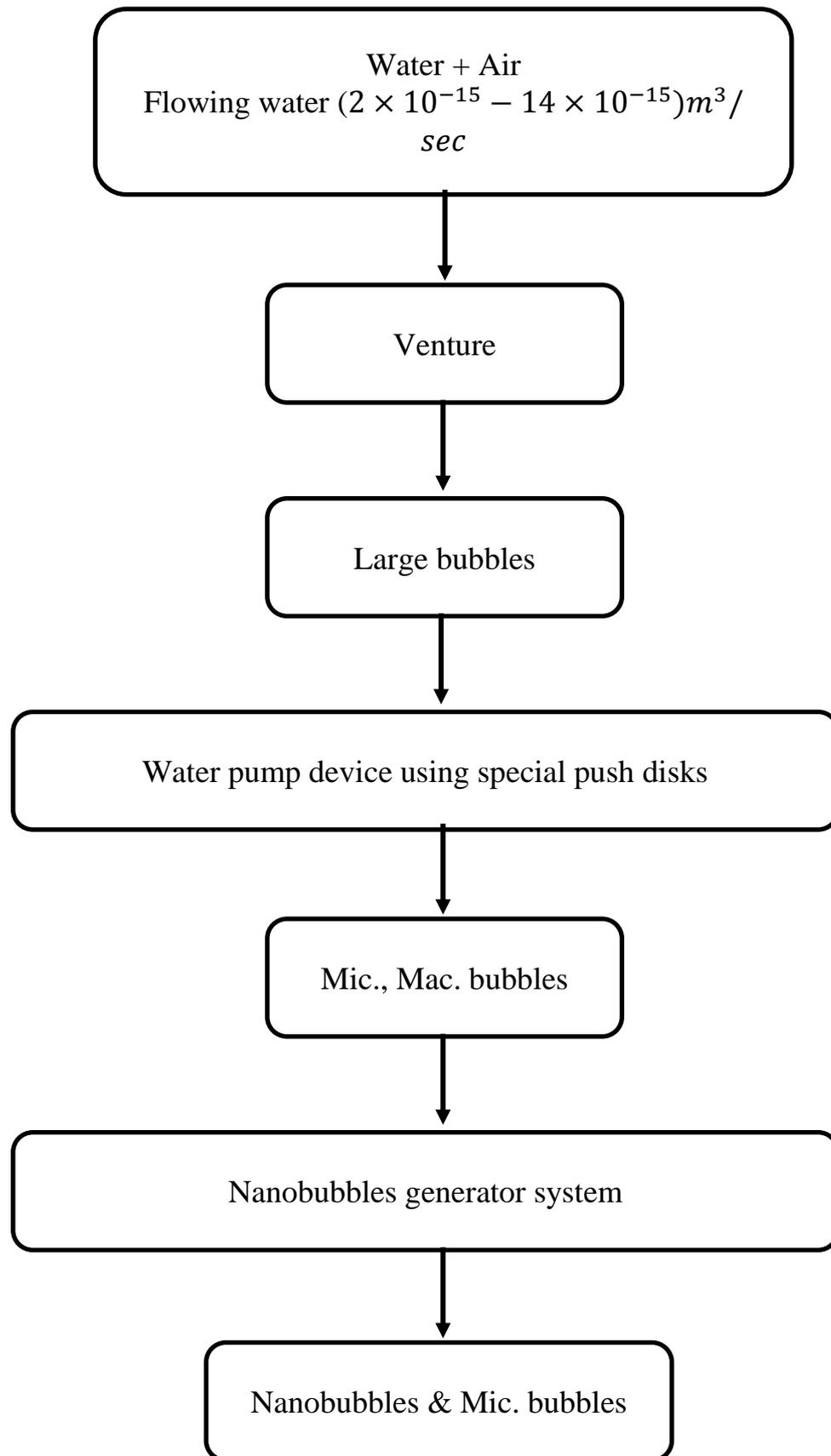


Figure (3-1) A scheme explains the phases of the production of nanobubbles.

The method of work:

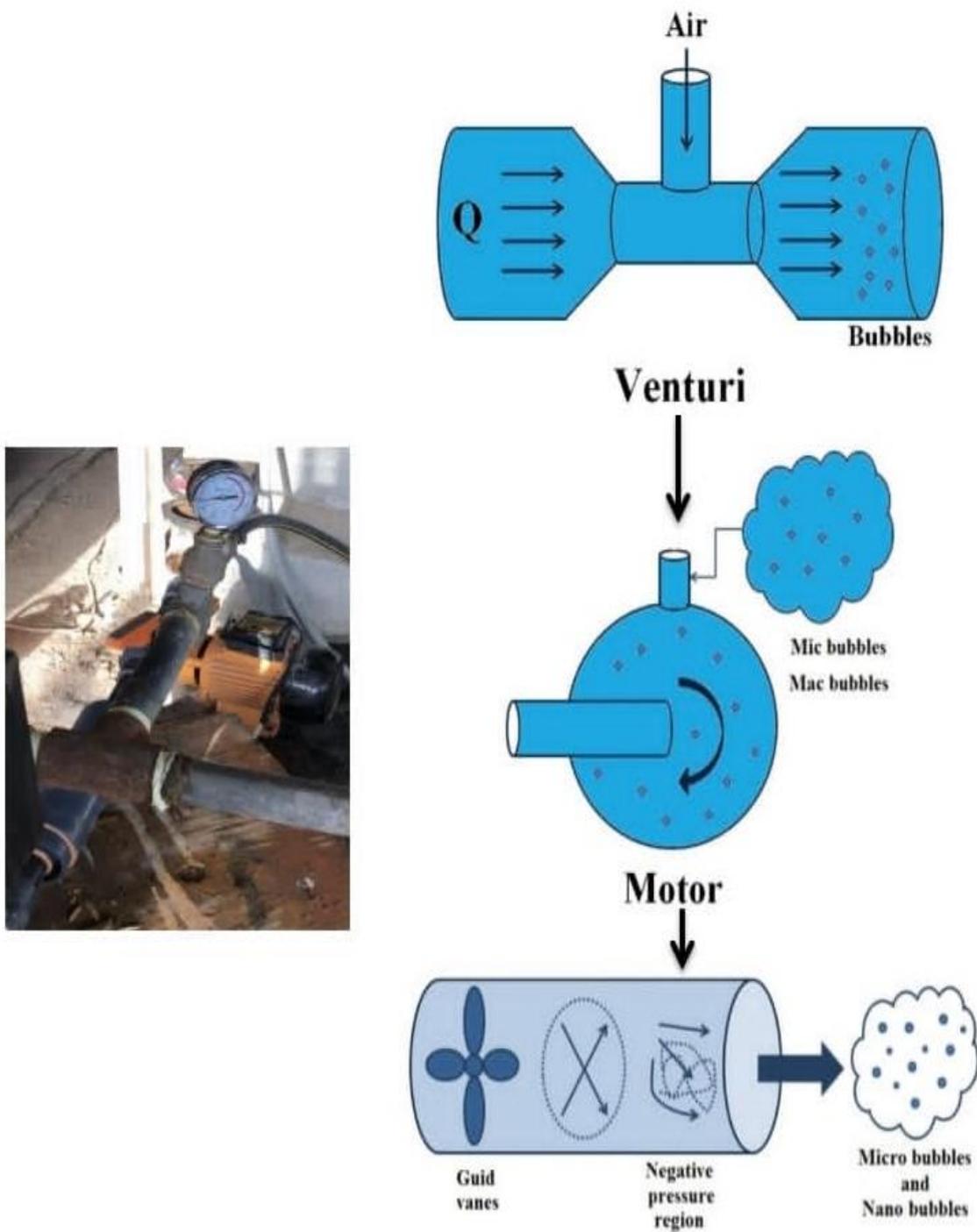


Figure (3-2) Design of the Nanosubject unit, which consists of the three stages and with flowing water ( $2 \cdot 10^{-15} - 14 \cdot 10^{-15}$ )  $\text{m}^3 \text{sec}^{-1}$

The nanobubbles are generated by the flow of water through a venture device under a pressure of (0.1, 0.11, ..., 0.2) MPa as shown in Figure (3.2) where the bubbles are formed, and then transferred to another water pump device using special push disks where a group of micro and macro bubbles are formed. Then, it goes to the nano bubble generator to produce a mixture of nano and micro bubbles.

### **3-3 Measure the percentage of dissolved oxygen in water**

Using a water dissolved air meter[Model JPB 607 Portable Dissolved Oxygen Analyzer].

The device can be divided into two parts, the sensor and the electronic unit. Membrane type sensor electrode and electronic unit is high integrated circuit. There is a liquid crystal display in the sensor and the device that can display the air ratio and temperature as in the Figure (3.3).

First, we calibrate the device before using it as follows:

1. We remove the sensor cover, dip it in  $\text{Na}_2\text{SO}_3$ , and wait 15 minutes for the device reading to stabilize before selecting the zero option and zeroing the reading value.
2. We put the lid on again and leave the device for 5 minutes, then turn the reading into a temperature and measure the temperature.
3. We press the readout according to the temperature from behind the device on the table.
4. The machine is now ready for testing samples. As in Figure (4).



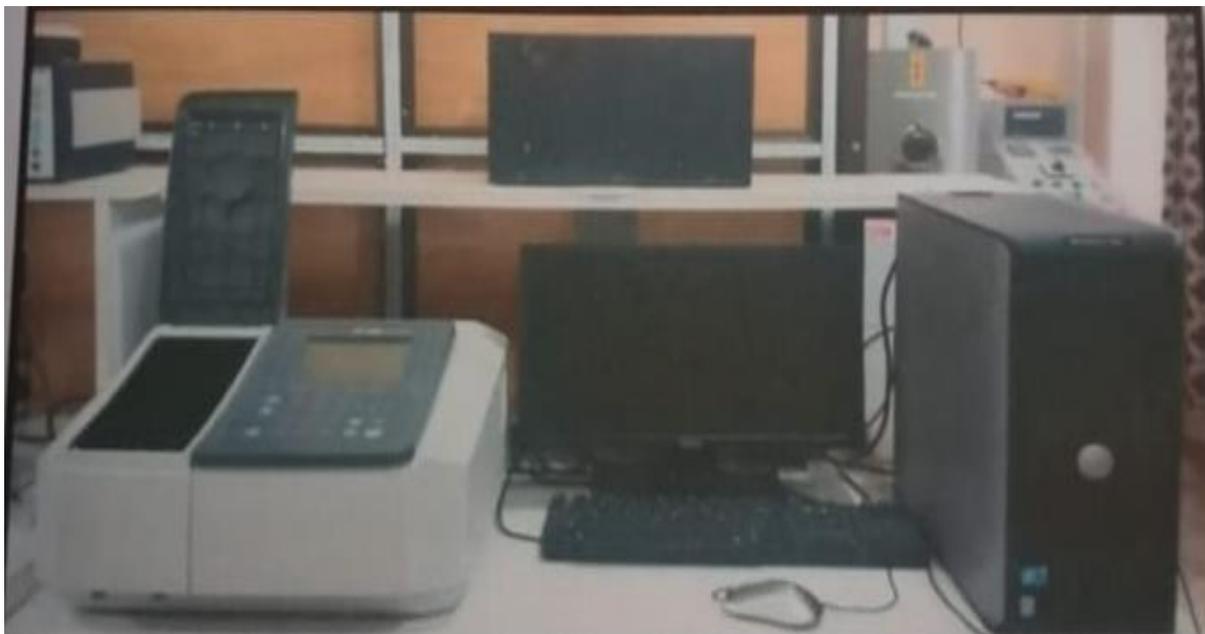
**Figure (3-3) A device for measuring the percentage of dissolved oxygen in water**

A device was used to measure the amount of dissolved air in water for natural water and water containing nano bubbles, after calibrating the device, measuring the temperature and adjusting the device's reading according to the temperature, as in Figure (3-3). We take a sample of natural water and immerse the sensor in the sample and wait for 5 minutes until the reading stabilizes the reading is recorded and found (3 mg/L), then we repeat the same method on the nanobubbles water sample and we record the reading and found at a rate of (29mg/L), which indicates the presence of infinitesimal bubbles and bubbles Nanobubbles.

### **3-4 Measurement of optical properties:**

The absorption and reflectivity spectrum of natural water and water containing nanobubble bubbles in the wavelength range (80\_200nm) was recorded using a dual beam spectrophotometer (Shimadzu Model (uv\_1800A Japan) at the University of Babylon / College of Education

for Pure Sciences / Department Physics The absorbance spectrum was recorded at room temperature a computer program was used to obtain the optical properties , the absorption coefficient, and the reflectivity factor.



**Figure (3-4) UV-Visible spectrophotometer "ShimadZu-1800"**

### **3-5 Bubble volume analyzer device**

A floating through with a valve and a sampling tube was used to image the ultrafine bubbles. A light source is mounted underneath the sample, and a camera is placed in front of the sample to photograph the microscopic bubbles. The work necessitates the ability to track moving bubbles for at least 30 frames with a spatial resolution of at least 35 pixels / mm; additionally, the bubble surface must fluctuate or change shape, as the camera is set at 500 images per second and the image size is 1280 x 1024 pixels. The image resolution ranges from 45 to 60 pixels / mm to track bubble surface fluctuations, as in Figure (3.5)

A digital high-(HR) camera was used to meet these specifications.

Image sequences can be merged in the AVI file format, and groups can be formed.

There are a variety of image sizes (number of pixels) that can be made. The valve opens, allowing bubbles to rise to the viewing chamber through float and disperse, reducing bubble disturbance and ensuring sufficient concentration. A batch of nanobubble water images is shot with great

speed and transparency for several minutes. As shown in Figure(3.6), the majority of the bubbles present are infinitesimal and microscopic bubbles

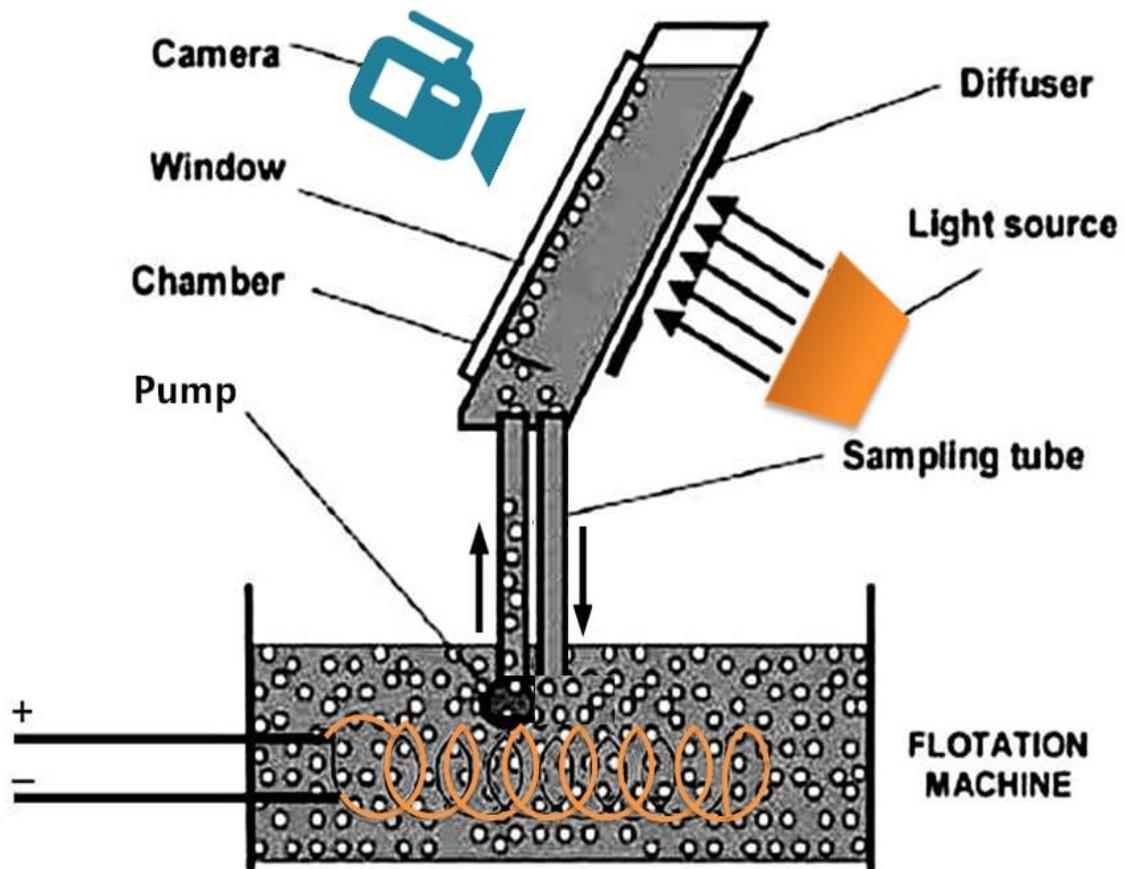


Figure (3-5) schematic diagram of a bubble volume analyzer [The devices were manufactured in Al-Ithmaar Agricultural company LTD/Iraq "locally manufactured"]

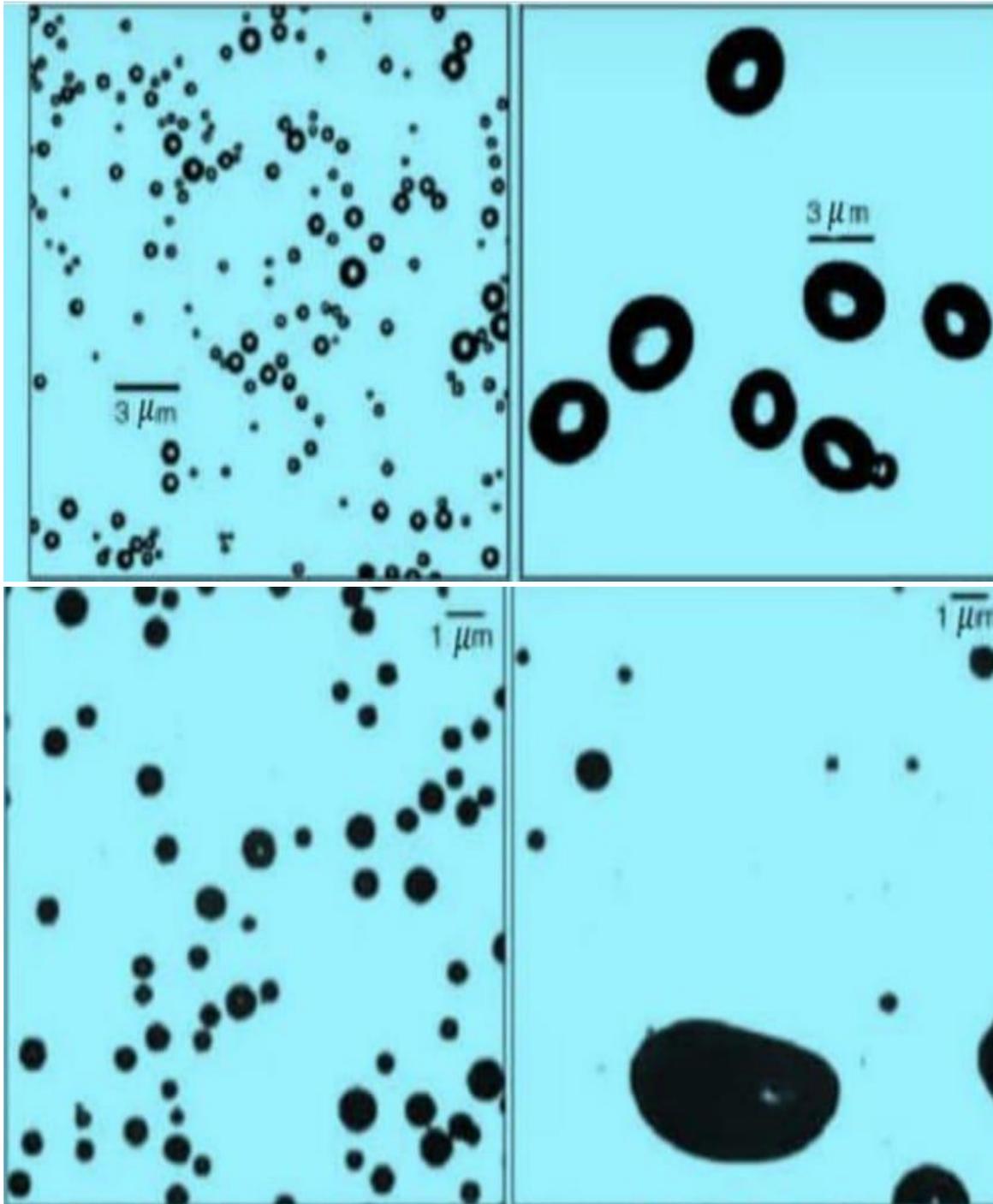


Figure (3-6) The sizes of infinitesimal bubbles.

# ***Chapter Four***

## ***Results***

#### 4-1 Introduction:

The return of water to its normal state, which is characterized by a homogeneous mixture of air and oxygen with the fluid (water), and this ratio comes into discussion and the type of use in many areas and sometimes requires a high homogeneity of oxygen and its survival dissolved, is the most important topic in restoring the vitality of water fresh for long periods to take advantage of it in its maximum forms and the simplest way is to reach Nano bubbles that are overlapping and fixed by specific efforts in the water fluid and that process lies in three separate stages.

At the beginning venture device is an application of the Bernoulli rule to mix large bubbles of air or any gas used with the fluid.

The gas is obtained by lowering the pressure than the atmospheric pressure in the area of the tube cavity, and thus the gas is withdrawn directly and without exerting any energy. Only here we use the water pressure capacity and then start the second stage, which is the transformation of the large bubbles into micro scales and mixed bubbles through the disk of the water pump in opposite geometric directions with respect to the fan is shaped with a speed limited to (1450 cycle per minute) and is done through tubes consistent with the exerted pressure of the aqueous fluid, which produces bubbles.

The bubbles is homogeneous with the water in its macro and micro scales form, which is less floating than the large bubbles produced from the first stage, and this time difference is within a few seconds, then the aqueous fluid mixed with these bubbles runs through appropriate tubes with the amount of flow ( $2 \times 10^{-15} - 14 \times 10^{-15}$ ) m<sup>3</sup>/sec) which determines the ratio of pressure at room temperature to the stage .

The final stage, which is the stage of forming nano bubbles, and the device is a tube with a diameter of 10 cm that initially contains tubes with a diameter of 20 cm spiral and with metallic roughness that controls the viscometer through friction between metal and water with different paths and a horizontal distance of 20 cm and then enters an area containing a group of fans which there are (15 fans) in number, as it begins to break the microscopic bubbles into different parts, including it

produces bubbles with nano bubble diameters as a result of the coefficient of adhesion and attraction of the molecular effort to maintain the shape of The nanobubbles, whose path is under pressure (1.4 Pa), produce a mixture of micro and nanobubbles. The water containing the ultrafine and ultrafine bubbles is left for several hours before being flattened and measured by a spectrometer. The invisible ratio was 0.21 after it was measured by optical devices in an optical spectrometer and confirmed by a chemical correction device for measuring the percentage of dissolved oxygen in water.

These results are close to the results of Bahaa h rabee [51], where the percentage of dissolved oxygen in water was around 24% using ultrasound.

## **4-2 Optical properties:**

The primary purpose of studying the optical properties of natural and nanobubble waters is to identify and recognize the presence of nanobubbles in water. The absorption and reflectivity spectrum was recorded at room temperature. Where the percentage of presence of nanobubbles in water that contains nano bubbles and natural water is recorded in this research through the optical properties [81] of a spectrophotometer that uses wavelengths (198-1100 nanometers).

The quartz glass is used to put natural water and nanobubble-containing water samples. ((because quartz has the property of non – absorption Or reflection).

### **4-2-1 Reflectivity:**

In this research we used a new method to extract the percentage of dissolved air in water, which depends on the reflectivity and absorption of the invisible nanobubbles dissolved in the water. The quartz glass use to preserve the water that contains the bubbles, the first stage was diagnosed after the flow and mixing of a quantity of air in the venture stage venture the second stage by using the special disk in water pump and to convert large bubbles into micro bubbles dissolved, and then the last stage to form a mixture of micro and nanobubbles dissolved in water.

We used this method with its conformity with the (D.O.) correction method. The readability and increase of the reflectivity is an indication of an increase in the percentage of oxygenation and that this increase in the reflectivity of the wavelength specified between (200-250nm) reveals and determines the proportion of dissolved air in the water, which is identical to the D.O. correction process the classic (29 mg/L).

The reflectivity of fresh water and water containing nanobubbles was recorded, where the reflectivity appeared in the water with a wavelength between (200-250nm) , as in Figure (4.1) and Figure (4.2). The contrast of reflectivity with the wavelength.

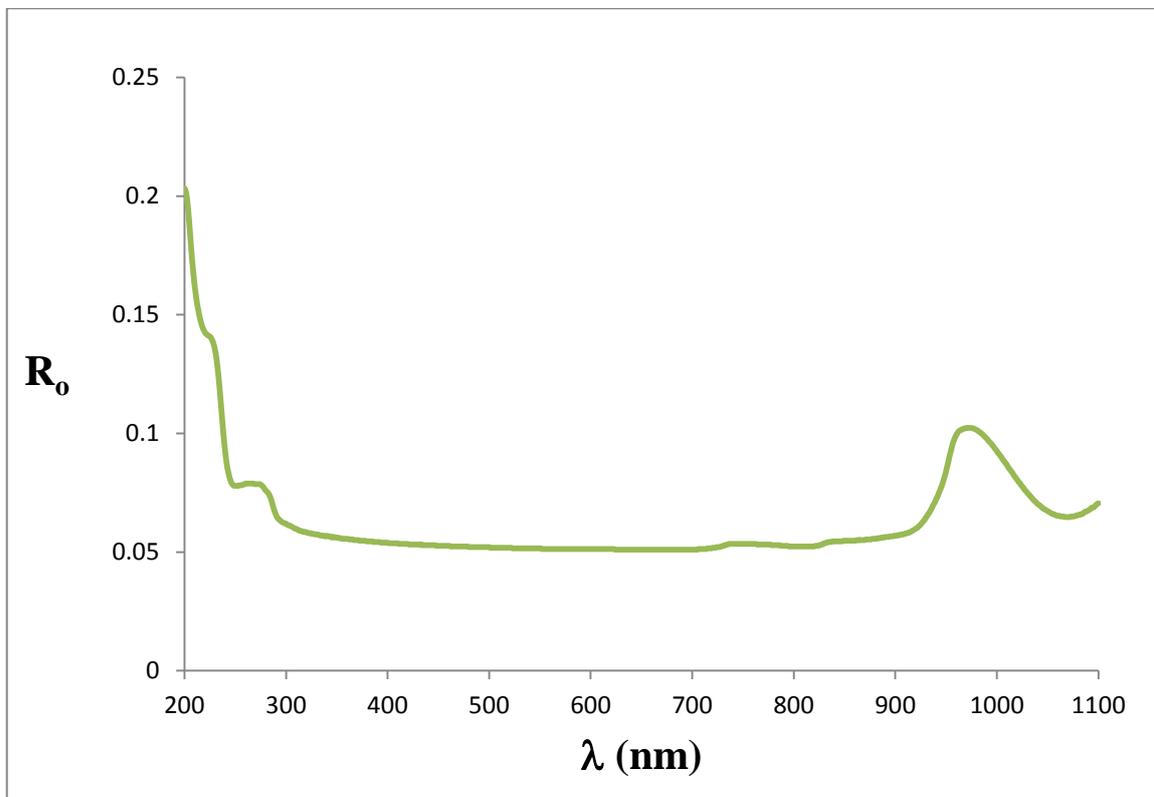
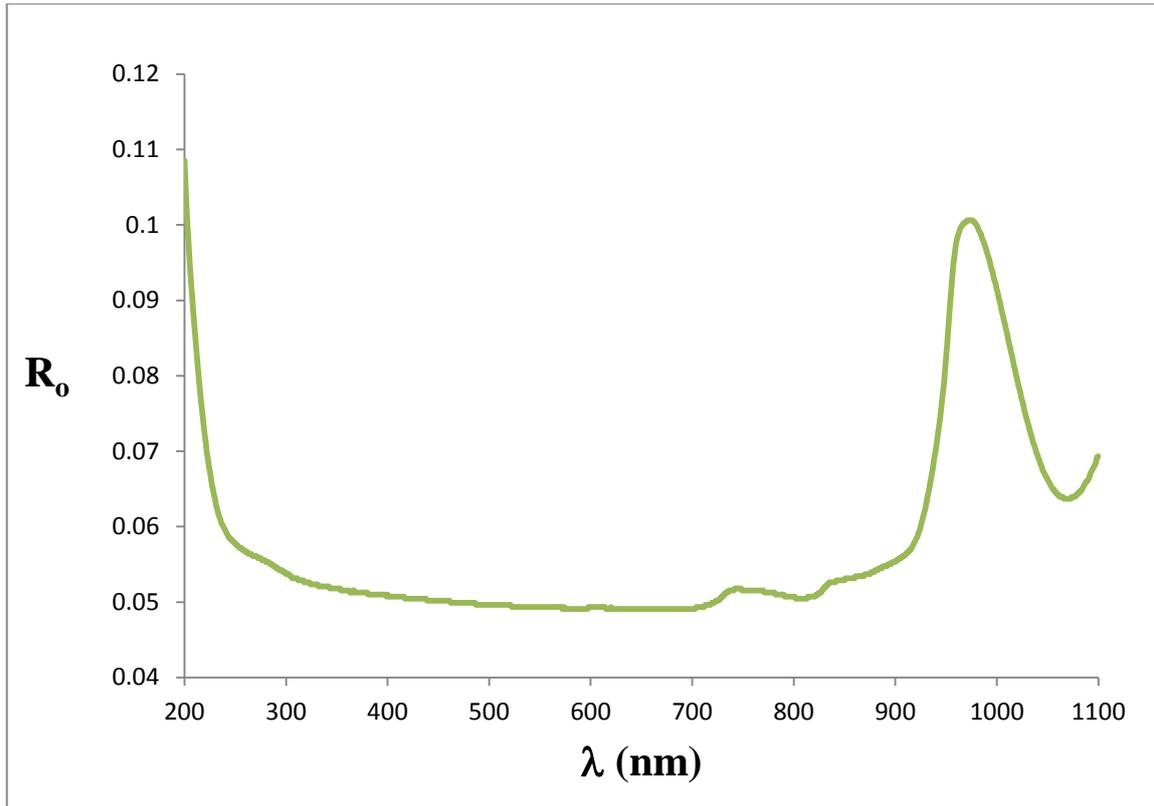


Figure (4-1) Reflectivity in nanobubbles



**Figure (4-2) Reflectivity in fresh water**

Through the numbers, it can be seen that it shows a greater degree of reflectivity in the ultraviolet region with respect to the nanobubble water, due to the reflection of the spectrum falling on the nanobubbles due to the separating surface between the water molecules and the air bubble which indicates the melting of the nanobubbles inside the water and the infinite reflectivity unlike the water. Natural, has very little reflection

#### **4-2-2 Transmittance ( $T_o$ )**

The permeability is calculated from equation (2- 28), Figures (4-3) and (4-4) illustrate the transmittance as a function of the wavelength of fresh water and water containing nanobubbles respectively. The numbers indicate that the transmittance of fresh water is large compared to Water containing nanobubbles , because there are fewer nanobubbles in the water, as a large part of the rays penetrate without being reflected.

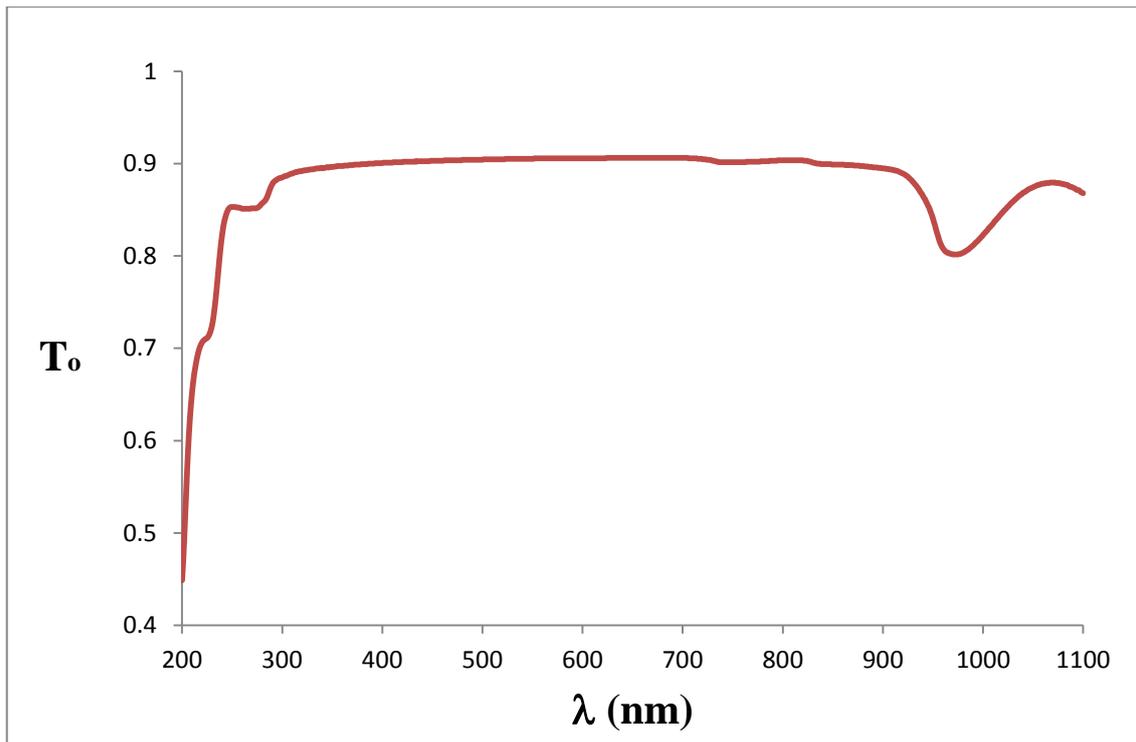


Figure (4-3): Transmittance in nanobubbles in water

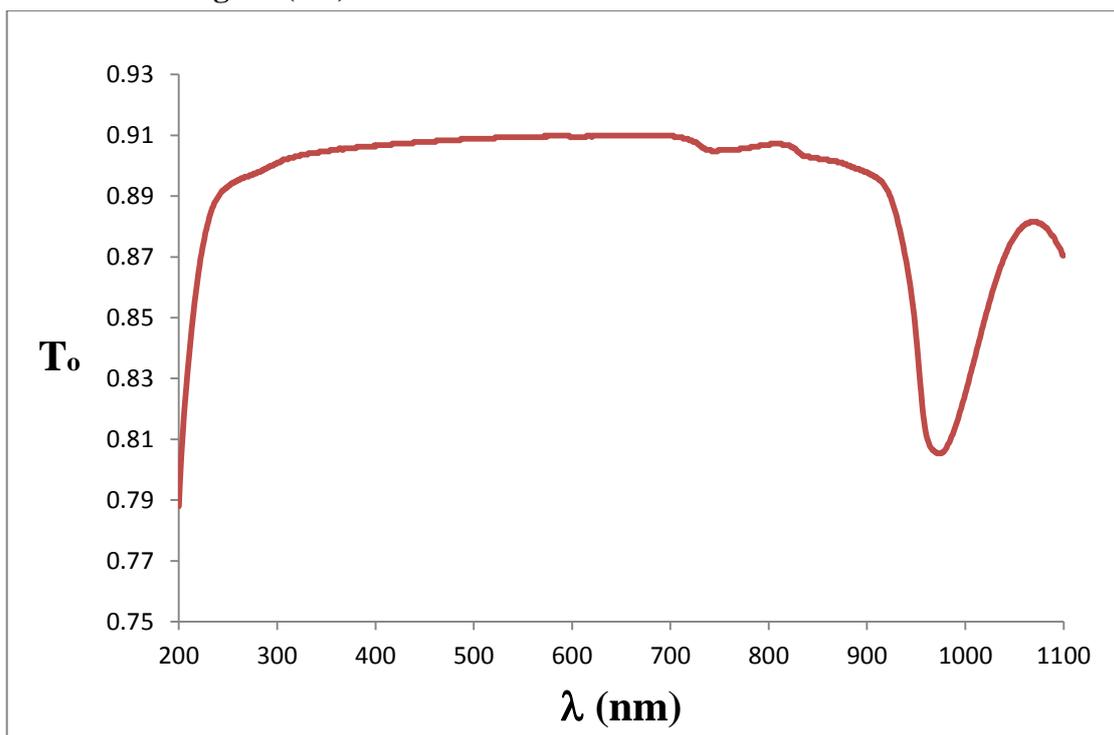


Figure (4-4) Transmittance in fresh water

### 4-3 Measuring the rate of cooling and heating

Heat treatment of the nanobubble bubbles may be used to investigate their thermal activity. An electric heater was used for the heat treatment. A 60 mL sample was taken in a borosil glass flask and heated

at a constant temperature, one with nanobubbles and the other without nanobubbles (medium mode). The temperature of the samples was measured using mercury in a glass thermometer.

The initial and final temperatures, as well as the time it took to heat and cool, are registered. Table (4.1) shows the time taken for each sample, with the aqueous solution of the nanobubbles taking the longest during the heating process.

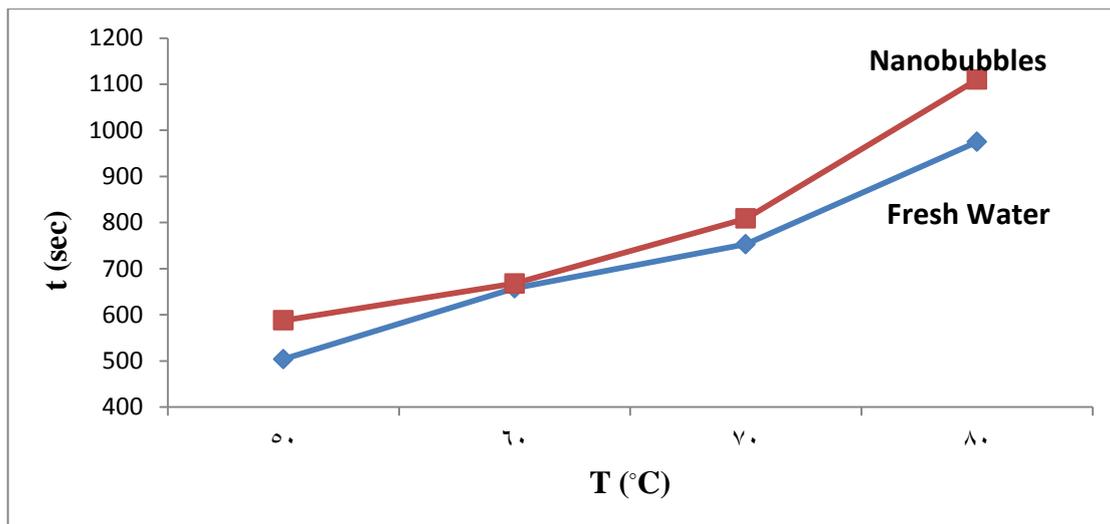
For a small temperature shift, the difference in time was very slight, but for a significant temperature change, there was a lot of variance. The aqueous solution of the nanobubbles took longer to heat as a result of the constant heat. The mechanism of heat transfer takes time because of discontinuity of the medium due to vacuum nanobubbles. Mobility of the water molecules with

nanobubbles increased, Owing to the disruption of the medium or the nanosphere, the heat transfer process takes longer to achieve equilibrium, so it takes longer to heat up the water with nanobubbles higher than regular water. In comparison, it takes 53 seconds. Figure 6-4 portrays a graph of temperature vs. time taken for samples to achieve precise temperatures at the nanobubble and macroscale, as in Figure (4.5)

The time it takes to heat up the nanobubbles containing water is represented by the red dots, while the time it takes to heat up fresh water is represented by the blue dots. By looking at the graph, it was discovered that the presence of nanobubbles increased the time it took to heat the water.

**Table (4.1) Time for heating the nanobubbles**

temperature interval / $^{\circ}$ C	time taken without nano-bubbles / sec	time taken with nano-bubbles/sec
50	504	588
60	657.6	667.8
70	753	808.8
80	975	1110



**Figure (4-5) is represented as a graph between the temperature and the time taken for samples**

The time taken to cool the water containing the nan bubbles was shorter than the time taken to cool the water without the nanobubbles, as shown in Table (4.2).

At low temperatures, there is no difference in time, but at high temperatures, there is a major difference. Water containing nanobubbles took longer to heat up because it rejected static heat. Since sufficient heating of the water containing the nanobubbles equals energy savings, and the vapor envelope receives an energy balance from the energy of the particles lost by conducting to the cooler liquid outside due to the faster cooling rate than the water The nanobubbles are suspended in water.

The time it takes to cool water with nanobubbles, as shown in Table (2), is expressed in Fig. (4-6) This graph depicts how long it takes to reach a specific temperature with or without nanobubbles. The red points show how long it takes to chill nanobubble-containing water, while the blue points show how long it takes to cool fresh water. And by drawing, that the presence of nanobubbles induces a major reduction in time.

**Table (4.2) Time for cooling the nanobubbles**

temprature intnterval /°C	time taken without nano-bobbles / sec	time taken with nano-bobbles/sec
70	246	204
50	1767	1291.8
34	3006	2184

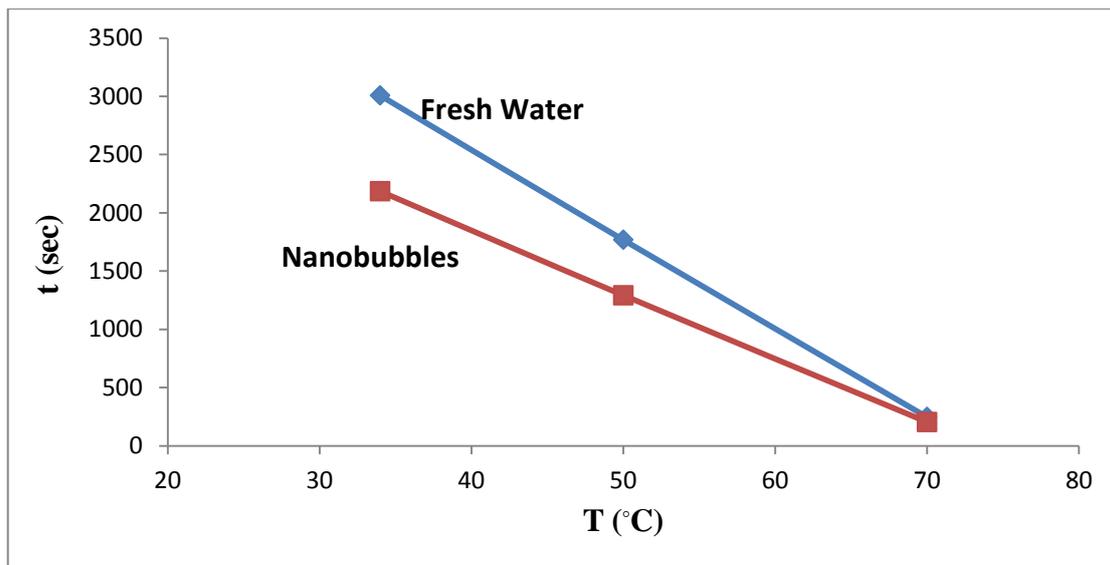


Figure (4-6) Showing the time taken to cool pure water and water containing nanobubbles

#### 4-4 Calculate the pressure, radius and volume of the bubble theoretically

Through the theoretical results, we notice that the smallest diameter of the nanobubbles is obtained when the surface area of the bubble is (0.041m) according to the equation(2-15), as in Figure (4.7).

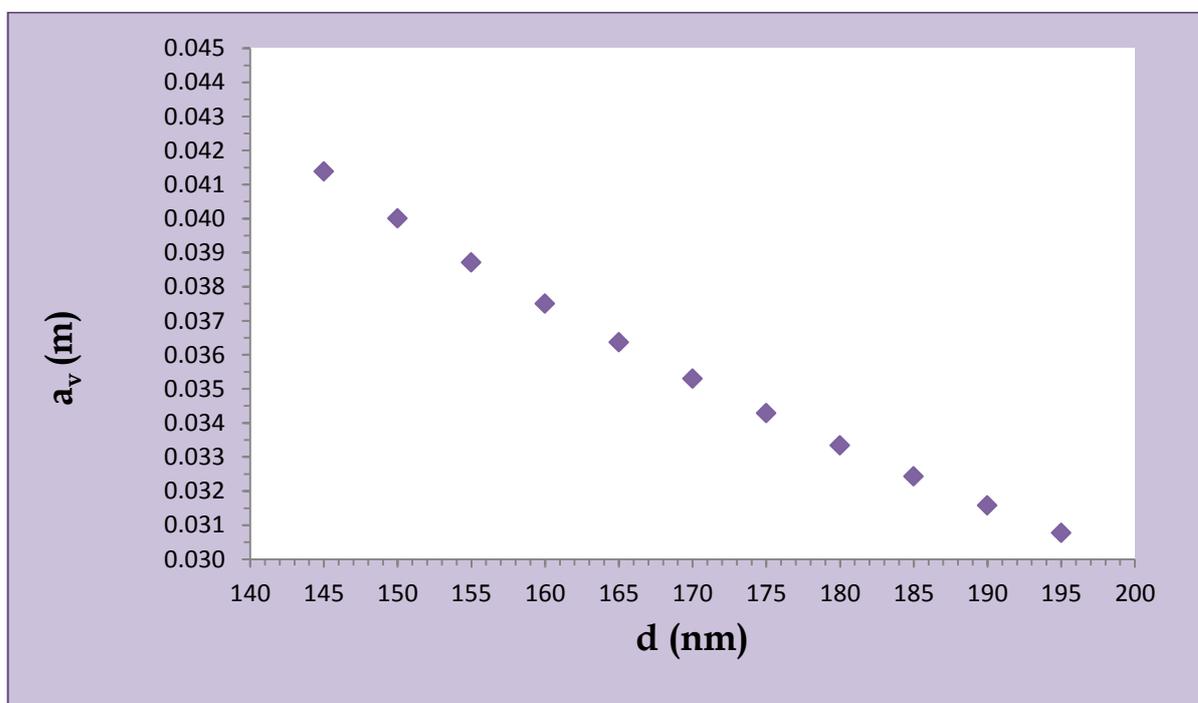
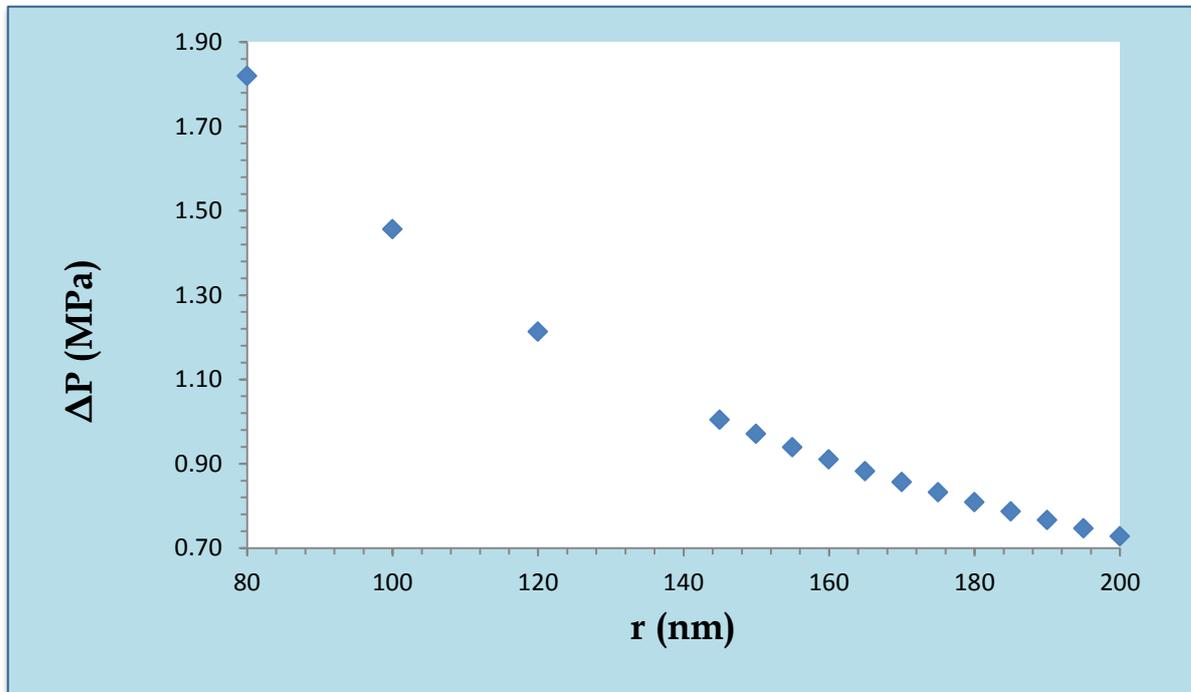


Figure (4.7) indicates the relationship between the bubble's diameter and the bubble's surface area.

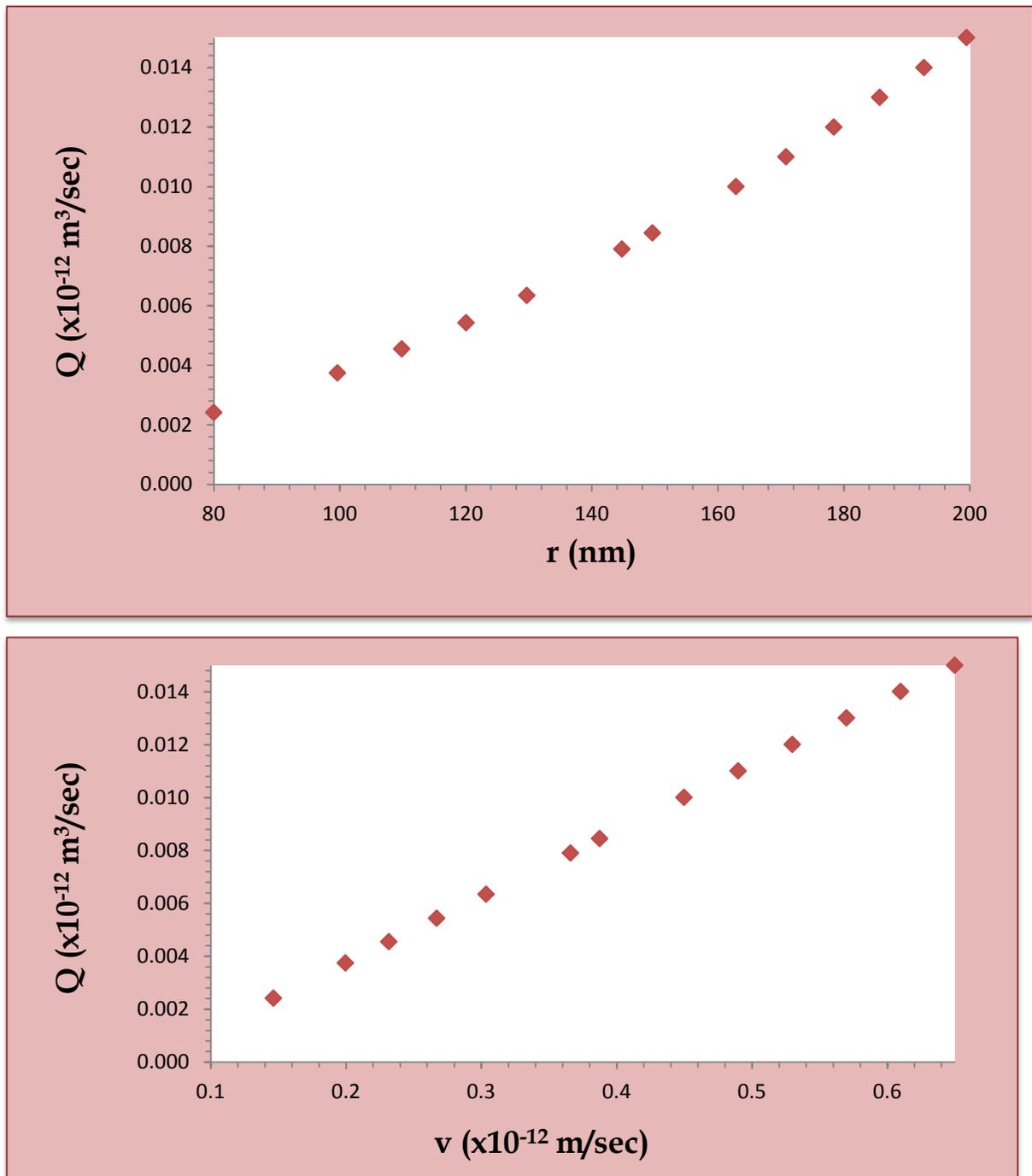
In geometry, the area can be defined as the space occupied by a flat shape or the surface of an object. The area of a figure is the number of unit squares that cover the surface of a closed figure. Area is measured in square units such as square centimeters, square feet, square inches, etc.

The change of the amount of the flowing water produces a variable pressure inside the system after using tubes made of polyethylene with nanocarbonate silver the specification of the tubes used can be adapted to the capacity of the tubes, as well as to control the viscosity of the tube with the water [81] which showed an upward change with the high pressure used ( on the water (0.78, 0.9-1.82) MPa according to the equation(2-11), as in Figure (4.8) with:



**Figure (4.8) shows the relationship between pressure change and bubble radius**

We notice that the radii of the nanobubbles range between (80-200) nm and the smallest radius we get at the pressure (1,820) MPa . As for figure (4.9).



**Figure (4.9) indicates the relationship between the amount of flow, the bubble's radius, and the bubble velocity.**

It shows the relationship between the of velocity and radius of the nano bubbles with the area constant  $0.025\text{m}^2$

Where a radius of about 80nm is obtained when the quantity of flux is 0.02. the velocity of the bubble also increases with the increase in the amount of flow, as the amount of flow is proportional to the velocity .

And the last results are the relationship between the size and the radius of the bubble, as we get the largest radius when the size of the bubble is  $34 \times 10^{-21} \text{ m}^3$ . according to the equation(2.28), As in figure (4.10) confirmed by the results in [51] .

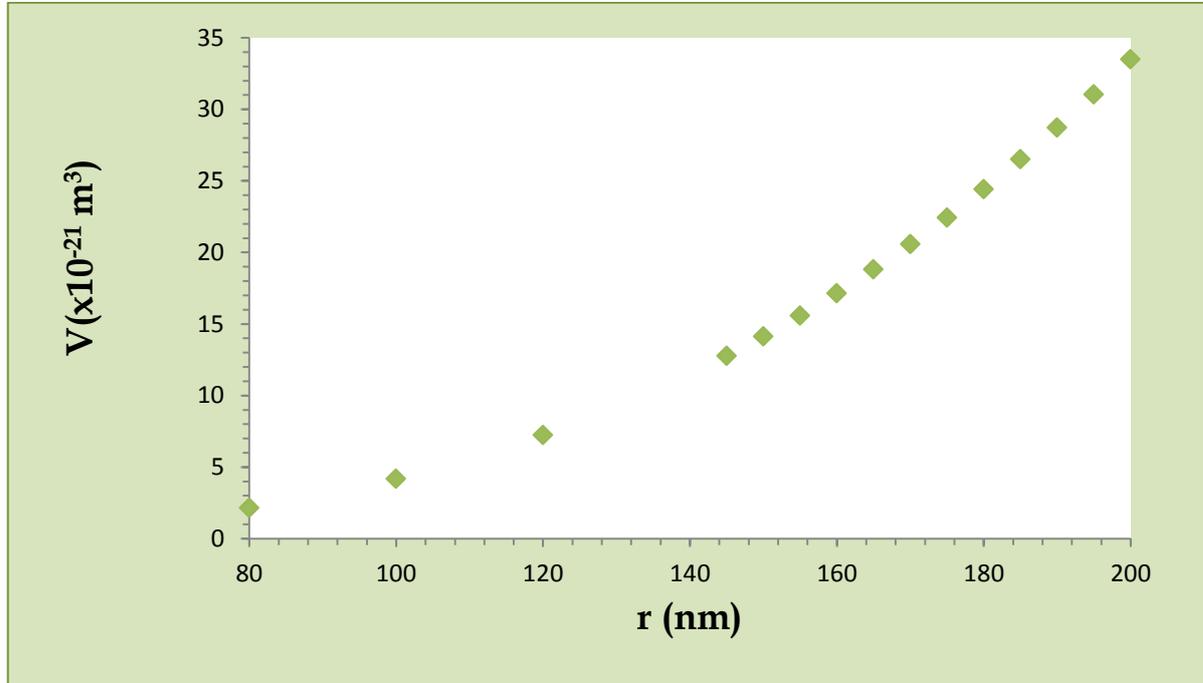


Figure (4-10) shows the relationship between the bubble radius and bubble size

**4-5 Conclusions:**

- 1- The highest percentage of nano bubbles dissolved in plain water, which reached 29 mg/L, was generated in three stages: the first stage, which involved combining water and gas with a venturi system and creating large bubbles; the second stage, which involved passing through the pump and forming microbubbles; and the third stage, which involved passing through a device. The formation of nano bubbles, which are a combination of micro and nano bubbles
- 2- The spectrometer, which operates at a wavelength of (198-1100) nanometers, for ultraviolet rays can be used to detect the presence of nanoscale bubbles dissolved in plain water, in which they show a high reflectivity that exceeds that of ordinary water.
- 3- The transmittance of water containing nanobubbles is lower than that of fresh water.
- 4- The best ratio can be achieved by converting the micro-bubbles into nanobubbles under the pressure of (0.1, 0.11,....., 0.2) MPa.
- 5- The specific area of the nanobubbles is inversely proportional to the radius of the bubble.
- 6- The relationship between pressure and radius inversely until it reaches a pressure of 1,820 MPa.
- 7- The relationship is positive between the velocity and the radius of the nanobubble.
- 8- The amount of water flow is directly proportional to the radius of the nanobubble and the velocity of the nanobubble.
- 9- The proportion of nanobubbles changes directly with the increase in the temperature, which is between (40-80) degrees Celsius.
- 10- nanobubbles remain for the longest period of time dissolved in water at low temperatures, which range between (204-2184) seconds at temperatures (34-70) degrees Celsius.

**4-6 Future work.**

Other future work may be adopted from this report, as suggested below:

1. The percentage of the deluge of nanobubbles in the water changes with time and temperature
2. The influence of changing the size of nano bubbles within the water on their deluge over time.
3. Measuring the zeta potential of nano water.

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وزارة التعليم العالي والبحث العلمي

جامعة بابل

كلية التربية للعلوم الصرفة

قسم الفيزياء

# سلوك الفقاعة النانوية عند تغير الضغط الهيدروليكي ودرجة الحرارة في المياه العذبة

رسالة مقدمة

الى مجلس كلية التربية للعلوم الصرفة جامعة بابل

كجزء من متطلبات نيل درجة الماجستير في التربية/ فيزياء

من قبل

زينب حيدر جواد حسن

بكالوريوس علوم فيزياء

جامعة بابل (٢٠١١)

بإشراف

أ. د. بهاء حسين صالح ربيع

## الخلاصة:

تم توليد فقاعات النانوية من خلال نظام ميكانيكي يحتوي على ثلاث مراحل وهي توليد فقاعات كبيرة الحجم بجهاز الفنتوري، عن طريق قاعدة برنولي في اختلاف الضغوط.

ثم يبدأ بتحويل الفقاعات الصغيرة الناتجة عن طريق مضخة مياه عكسية الاتجاه إلى فقاعات دقيقة، ثم تحويلها من خلال جهاز توليد الفقاعات النانوية الذي يحتوي على أنابيب برمية ومراوح عكسية والذي ينتج خليط من الفقاعات النانوية و المايكروية والتي تتراوح بأقطار (80-200 نانومتر) بالنسبة للفقاعات للنانوية، و (200-1200 مايكرومتر) بالنسبة للفقاعات للمايكروية.

ثم تم اثبات وجود الفقاعات النانوية عن طريق جهاز التسحيح D. O والتي تصل نسبة الفقاعات النانوية المذابة بحدود 29 مليغرام/التر في الماء العذب وقد وجدنا طريقة جديدة لحساب نسبة الفقاعات النانوية المذابة عن طريق جهاز المطياف البصري والذي يعمل بالأشعة فوق البنفسجية وبطول موجي (180-1180 نانومتر) حيث كانت الانعكاسية مميزة في المياه التي تحتوي على فقاعات نانوية عن المياه العذبة العادية.

تكون علاقة الانعكاسية طردية مع زيادة نسبة تواجد الفقاعات النانوية المذابة في المياه، وقد كان أفضل خرج لتدفق المياه عند الضغط يتراوح بين (7.0-9.1 ميكابسكال) وقد وجد أن هذه التغييرات تتفق مع الدراسة النظرية لتغير مساحة سطح الفقاعات النانوية.

ان أصغر قطر للفقاعة نحصل عليه عند الضغط (820.1 ميكابسكال) وايضا تكون العلاقة بين نصف قطر فقاعات النانو مع كمية التدفق علاقة طردية،

حيث تم الحصول على نصف قطر يبلغ حوالي 80 نانومتر عندما تكون كمية التدفق 0.02 تزداد سرعة الفقاعة أيضا مع زيادة كمية التدفق. وايضا نحصل على أكبر نصف قطر عندما يكون حجم الفقاعة حوالي  $(34 \times 10^{21})$  تم أيضا قياس الوقت المستغرق لتبريد وتسخين المياه التي تحتوي على فقاعات نانوية والمياه العذبة العادية حيث بينت النتائج أن الماء الذي يحتوي على فقاعات النانوية يستغرق وقت أقل لتبريد وبالتالي يمكن استخدامه في أجهزة التبريد، ومن خلال عملية التسخين المياه (20-80 درجة مئوية) وجد أن العلاقة بين الفترة الزمنية لطفو الفقاعات النانوية وهروبها من المياه تتناسب عكسيا مع ارتفاع درجة الحرارة.