

SUBSTANTIATION AND CHARACTERIZATION OF NANOBUBBLE FOR WASTE WATER TREATMENT

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in Mechanical engineering.

by

SATHISH KUMAR. G (37150169)
MANOWIN. N.K (37150116)



**DEPARTMENT OF MECHANICAL ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY) JEPPIAAR NAGAR, RAJIV GANDHI SALAI,

CHENNAI - 600 119

Accredited with Grade "A" by NAAC

MARCH – 2021

DECLARATION

We SATHISH KUMAR G (37150169) and MANOWIN N K (37150116) hereby declare that the Project Report entitled **“SUBSTANTIATION AND CHARACTERIZATION OF NANOBUBBLE FOR WASTE WATER TREATMENT”** done by us under the guidance of **Dr. G. SENTHILKUMAR M.E. Ph.D.** at **SATHYABAMA Institute of Science and Technology**, Chennai is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechanical engineering

1.

2.

DATE:

PLACE:

SIGNATURE OF THE CANDIDATE



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with “A” grade by NAAC

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119

www.sathyabama.ac.in



DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of SATHISH KUMAR G (37150169), MANOWIN N K (37150116) who carried out the project entitled “**SUBSTANTIATION AND CHARACTERIZATION OF NANO BUBBLE FOR WASTE WATER TREATMENT**” under our supervision from October 2020 to March 2021.

Internal Guide

DR. G. SENTHILKUMAR M.E., PhD.

External Guide

Head of the Department

Submitted for Viva voce Examination held on _____

Internal Examiner

External Examiner

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the Board of Management of SATHYABAMA for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to **Dr.S. PRAKASH.M.E.Ph.D.**, Dean, School of Mechanical engineering and **Dr.G. ARUNKUMAR,M.E.Ph.D.**, Head of the Department, Dept. of Mechanical engineering for providing me necessary support and details at the right time during the progressive reviews.

I would like to express my sincere and deep sense of gratitude to my Project Guide **Dr.G. SENTHILKUMAR, M.E.Ph.D.**, for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Mechanical engineering who were helpful in many ways for the completion of the project.

ABSTRACT

Although various and unique properties of nanobubbles have drawn researchers' attention over the previous couple of years, their formation and stabilization mechanism has remained unsolved., The intention behind this study is to understand the ultrasonic methods to produce nanobubbles in the various water and give a comprehensive study on the nanobubbles properties and generation. The ultrasonic wave gives rise to constant oscillation in water where positive and negative pressure appears alternately. With the induced cavitation and presence of dissolved air, the nanobubbles formed. The project enumerates the potential features of Nanobubbles (NBs) for the treatment of surface water without affecting the environmental circumferences. The formation of free radicals increased the surface area density with reduction in radius of NBs. The sustainability for prolonged duration, optimum interface potential, high oxygen transfer efficiency and ease of production methods increased the research in NBs in recent years. The surface water was treated for reduction in chemical oxygen demand, biochemical oxygen demand, total dissolved solids and total suspended solids with this unique NB technology and the results were highlighted. Also the promotion of dissolved oxygen in the selected water samples from tap, pond, domestic waste and sea after treatment with NBs were discussed.

.

CONTENTS

CHAPTER NO.	TITLE	Page No
	ABSTRACT	V
	LIST OF TABLES	X
	LIST OF FIGURES	XI
1	INTRODUCTION	1
	1.1 EARLY STUDIES ON NANO BUBBLE TECHNOLOGY	3
	1.2 FUNDAMENTAL PROPERTIES OF MNBS	5
	1.3 BASIC CHARACTERISTICS OF MNBS	6
	1.4 METHOD FOR GENERATING MNBS	7
	1.4.1 Pressurized dissolved gas release method	7
	1.4.2 Dispersed air method	8
	1.4.3 Electrochemical method	8
	1.4.4 Ultrasonic cavitation method	8
	1.4.5 Solution replacement method	9
	1.5 MNBS APPLICATION IN WATER TREATMENT	9
	1.5.1 Aeration process	9
	1.5.2 Floatation process	11
	1.5.3 Disinfection process	12
	1.6 ZETA POTENTIAL OF MNBS	12
	1.7 APPLICATION OF MNBS IN VARIOUS SECTORS	13
	1.7.1 Agriculture	14

	1.7.2 Aquaculture and fisheries	15
	1.7.3 Cellular Biological	15
	1.7.4 Industry Energy System	16
	1.7.5 Domestic Uses	16
	1.8 BUBBLE STABILITY IN THE ULTRA-SONICATION FIELD	17
	1.9 PRESENT STUDY	20
2	LITERATURE SURVEY	21
	2.1 INTRODUCTION	21
	2.1.1 Studies on Sound theory	21
	2.1.2 Studies on Cavitation	22
	2.1.3 Studies on Membrane Filtration	23
	2.1.4 Studies of Ultra sound for turbidity and total suspended solids reduction	25
	2.1.5 Studies of Ultra sound in Organic pollutants degradation	26
	2.1.6 Studies of Ultra sound for water disinfection process	27
	2.1.7 Ultra sound and chemical synergistic effect	28
	2.1.8 Sonication and Ozonation synergistic effects	28
	2.1.9 Ultrasound and Ultra violet synergistic effect	29
	2.2 SUMMARY OF LITERATURE REVIEW	29

3	AIM AND SCOPE OF THE PROJECT	30
	3.1 AIM OF THE PROJECT	30
	3.2 SCOPE OF THE PROJECT	30
4	MATERIALS AND METHODS	31
	4.1 METHODOLOGY OF RESEARCH	31
	4.2 MATERIAL REQUIRED	31
	4.2.1 Ultrasonicator	31
	4.2.2 Air Compressor	32
	4.2.3 Eliminator	33
	4.3 METHODS INVOLVED	34
	4.3.1 Nanobubbles produced by the Ultrasonic method	34
5	RESULT AND DISCUSSION	39
	5.1 LASER TESTING	39
	5.2 CHEMICAL OXYGEN DEMAND (COD)	40
	5.3 BIOCHEMICAL OXYGEN DEMAND (BOD)	41
	5.4 DISSOLVED OXYGEN (DO)	40
	5.5 TOTAL SUSPENDED SOLIDS (TSS)	41
	5.6 TOTAL DISSOLVED SOLIDS (TDS)	42
	5.7 TEST SAMPLE	43
	5.7.1 Sample no 1	43
	5.7.2 Sample no 2	44

	5.7.3 Sample no 3	44
	5.7.4 Sample no 4	45
6	SUMMARY AND CONCLUSION	48
	REFERENCES	47

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE NO.
1.1	Evolution of nanobubble technology	3
1.2	Properties of nano bubble	6
1.3	Stability of bubbles	20
4.1	Flow Chart depicting the Research Methodology	32
4.2	Ultrasonicator	33
4.3	Air compressor	34
4.4	Eliminator	35
4.5	Ultra sonic nanobubble generator	37
5.1	Laser testing	39
5.2	Chemical oxygen demand (cod)	40
5.3	Biochemical oxygen demand (bod)	41
5.4	Dissolved oxygen (do)	42
5.5	Total suspended solids (tss)	43
5.6	Total dissolved solids (tds)	44

LIST OF TABLES

TABLE No	TITLE	PAGE No.
5..1	Test report for before and after the presence of nanobubbles in sample no 1 (Tap water)	45
5..2	Test report for before and after the presence of nanobubbles in sample no 2 (Pond water)	46
5..3	Test report for before and after the presence of nanobubbles in sample no 3 (Domestic Waste Water)	46
5..4	Test report for before and after the presence of nanobubbles in sample no 4 (Industrial Waste Water)	47

CHAPTER 1

INTRODUCTION

Sonicated nanobubbles have drawn researchers' attention within a previous couple of years. Ultrasonic nanobubbles are spherical gas bubbles with a mean diameter of quite less than a thousand nanometers. probably the earliest evidence of bulk nanobubbles with diameters of but one μm was reported by Johnson and Cooke in 1981. Following this work, very little was revealed on bulk nanobubbles till the Nineteen Nineties, once Bunkin et al reported the existence of stable microbubbles in dilute solutions of electrolytes. The new millennium brought a burst of publications on nanobubbles. However, these experiments are properly criticized for an absence of evidence that the nanoparticles being ascertained truly incorporates gas whereas the surface nanobubbles are directly imaged via atomic force research (AFM) in 2000 and nanobubbles' distinctive properties like a long time and extremely air mass within in line with Yong-Laplace equation have LED to reports nanobubbles being treated with nice caution as a result of no physics stability are feasible in classic theory. Maybe the foremost evidence that nanobubbles that incorporate gas were given by Kobayashi in 2014. Bunkin et al. used a modulation interference magnifier to image nanobubbles in common salt solutions. In summary, proof that bulk nanobubbles are so gas-filled comes from a good vary of experiments. Despite the restricted quantity of analysis into nanobubbles, nanobubbles have already been shown to own potential in several applications, together with activity victimization nanobubbles are additionally being applied to the bioremediation of groundwater pollution and water treatment. Nanobubbles are presently being assessed for application to mineral separations victimization froth flotation. Another potential application is in depletion natural action for the dewatering of mineral tailings. nanobubbles are incontestible to effectively clean proteins from surfaces. The absence of extra surfactants implies that chemical residues don't seem to be a problem which the improvement method is probably going to be a lot environmentally friendly. Nano-sized bubbles are most popular in some applications as a result of they will be accustomed target the

capillaries outside the respiratory organ bed. Nanobubbles or connected entities have conjointly been involved in ventilated medical saline for the treatment of respiratory disorders and different response diseases with exceptional effectualness. From the experimental perspective, nanobubbles generation strategies embrace ethanol–Water exchange (E W exchange). Direct immersion, natural action, electrochemical reactions, cold water adding, and so on. However, these strategies largely generate surface nanobubbles and, to some extent, are difficult and expensive to work on or may herald contaminations. A technique to supply adequate Nanobubble remains to be discovered and therefore the ultrasound method may well be on paper potential. During this work, we tend to specialize in the distinctive cavitation property of supersonic waves in a very liquid resolution. Ultrasonic waves incorporate a series of horizontal and vertical mechanical waves that unfold equally within the liquid resolution. The molecules within the resolution perpetually oscillate in resolution wherever positive and negative pressure seems alternate, once wave density reaches a degree on top of the cavitation threshold, below the negative supersonic wave pressure, a cavitation nucleus forms between liquid molecules then dilate or shrink with the modification of supersonic wave. The pioneering analysis regarding ultrasound-induced bubbles may be derived back to 1962, which ended that high-energy neutrons may contribute to bulk water cavitation caused by ultrasound. Scientists in 2000 and 2005 reported the generation of nanoparticles by sonication (42 kilocycles, seventy W) within the presence of a palladium-coated surface in numerous resolutions, though in these studies nanobubbles can be hooked up to atomic number 46 coated conductor forming surface nanobubbles. The ultrasound mechanism is so possible to get nanobubbles. additionally, ultrasound may be a mature technique and comparatively easy to manage the parameter, which implies below sure conditions, we can manufacture adequate bulk nanobubbles for measuring. during this paper, we tend to introduce a technique to use cavitation induced by associate Ultrasonic wave to supply bulk nanobubbles and provides a comprehensive study on this method. First, we tend incontestible that the nanoparticles that we have a tendency to generated and measured are so bulk nanobubbles. By comparison the concentration of nanobubbles before and once

degassing and reduce of a dissolved element, we tend to make sure our assumption is correct. Then, we tend to study more into this development to live the nanobubbles' modification within the bulk resolution. we tend to found nanobubbles first reached a maximum value then weakened in quantity however accrued in size, wherever nanobubbles are distributed roughly even within the bulk resolution. Finally, we tend to explain the mechanism of Nanobubbles generation with Ultrasonic strategies. Consequently, we glance forward to seeing if our methodology may have broad application in varied fields

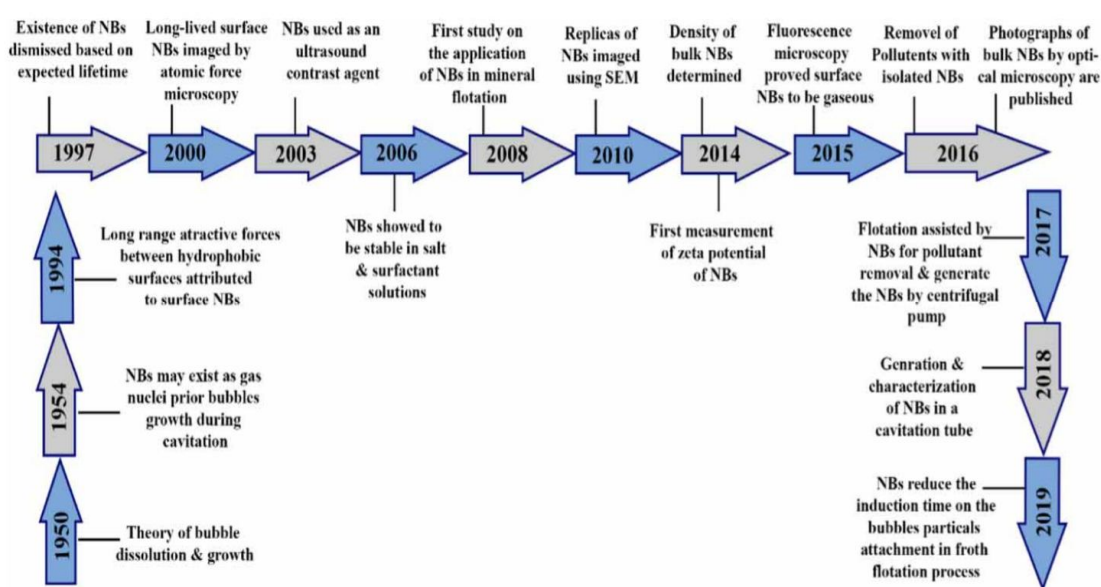


Fig 1.1: Evolution of Nanobubble Technology

1.1 EARLY STUDIES ON NANO BUBBLE TECHNOLOGY

The sustainability of all the organisms like plants, human and animals is the function of quality of water. The NBs were tiny gas bubbles in liquid medium with particle size ranges between 200 nm and 10 microns. The application of NB includes treatment of waste water, drug delivery, ozone treatment, marine operation, H₂ storage, seed germination activity, anti-microbial activity, aquaculture, sterilization of oysters and vessel cleaning though the research is in infant stage. The buoyancy force of NBs was found to be less than the large bubbles due to their particle size led them to sustain for even months. The MNB is a spherical air cavity in a liquid medium

and the surface area density $A/V=3/r$, (where A =Surface area of NBs, V = Volume of NBs, r =radius of NBs of spherical shape) the density increases with reduction in size of NBs. As the smaller bubbles subjected to large surface tension, leading for shrink and increase in more internal pressure inside the bubble cavity. If attempts were made to shrink the MNB to such low size, resulted in pressure applied to infinite causing collapsing of NBs. This results in formation of $\text{OH}^\cdot$ free radicals. The salient feature of $\text{OH}^\cdot$ ions is that it's oxidizing behavior and removal of pollutants such as phenol which is very hard to be removed by any other procedures. The zeta potential influences the stability of NBs directly. The NBs zeta potential (particle's electrical potential at the slip plane) ranges between -34mV and -45 mV for oxygen, -29mV and -35 mV for nitrogen, -20mV and -17 mV for air, -20mV and -27 mV for CO_2 and -11mV and -22mV for Xenon. The zeta potential directly influences the stability of NBs. The ability of dissolution of NBs was extremely more than that of normal large bubbles. Fan et al reported that the air NBs were spherical in shape when they exist in water medium. The DO % in water was increased with the presence of NBs in water. The NBs were long lasting without reduction in size for months. The presence of NBs also depended on pH of water and other salt contents if any. For a 100 nm bubble size, the normal Laplace pressure was around 30 N/m^2 . The water with NBs was found to be charged electrically and its zeta potential values were negative in all the O_2 , CO_2 , Xe and N_2 sample. Nanobubbles water curcumin extract might be one of the competent substitute nutrition used with exercises. The vacuum degasification method was employed for the production of bulk nanobubbles in ultra-pure water with the aid of a syringe. The Molecular dynamics simulation was employed to investigate the brownian movement of nanobubbles in deionized water. The ozone microbubbles were capable of removing pollutants which were organic in nature. The gas-oil engine with air nanobubbles contributed for energy savings. The physiochemical properties of water were influenced by the presence of Nanobubbles. The coalescence of nanobubbles generated was the function of temperature variations as predicted by response surface methodology.

1.2 FUNDAMENTAL PROPERTIES OF MNBS

Generally, water bubbles can be categorized into three major types, i.e., ordinary or macro bubbles, microbubbles (MBs), and nanobubbles (NBs). The diameter of macro bubbles ranges from 100 μm to 2 mm. These bubbles quickly rise to the surface of a liquid and collapse. While Microbubbles are smaller than macro bubbles with a diameter range of 1 μm –100 μm , these bubbles shrink in the water and then dissolve into it. In contrast, NBs are extremely small gas bubbles that have several unique physical properties that make them very different from normal bubbles. Generally, NBs range from $<1\ \mu\text{m}$ in diameters; however, the NBs, which are $<100\ \text{nm}$ in diameter, randomly drift termed as Brownian Motion and with a lower buoyancy can remain suspended in liquids for an extended period of time and have the ability to change the typical characteristics of water. Despite subsequent studies, there are still controversies over NBs size and its existence in the solution under atmospheric conditions. According to the classical thermodynamics' theory, NBs cannot exist or be stable due to the limitation of radius curvature. For instance, the small radius of curvature gives NBs a higher internal pressure relative to the external pressure, which leads to its rapid dissolution. For example, an NB with radius 100 nm (atmospheric pressure in the surrounding water $\frac{1}{4}\ 10^5\ \text{N m}^{-2}$ and surface tension $\frac{1}{4}\ 72\ \text{mN/m}$) gives an internal pressure of 1.5 MPa. The basic theory of this phenomenon is because high internal pressure contained in NB does not achieve balance with the atmosphere, which would inevitably lead to bursting bubbles in a very short time. First reported the existence of NBs as bright and stable spheres on a flat solid surface, through AFM (Atomic force microscopy). However, in recent years' various other methods have also been adopted for NB investigation such as neutron reflectometry, X-ray reflectivity and quartz crystal microbalance. One of the unique properties of NBs is stated their higher longevity, which gives them a larger contact angle and longer existence time in the liquid.

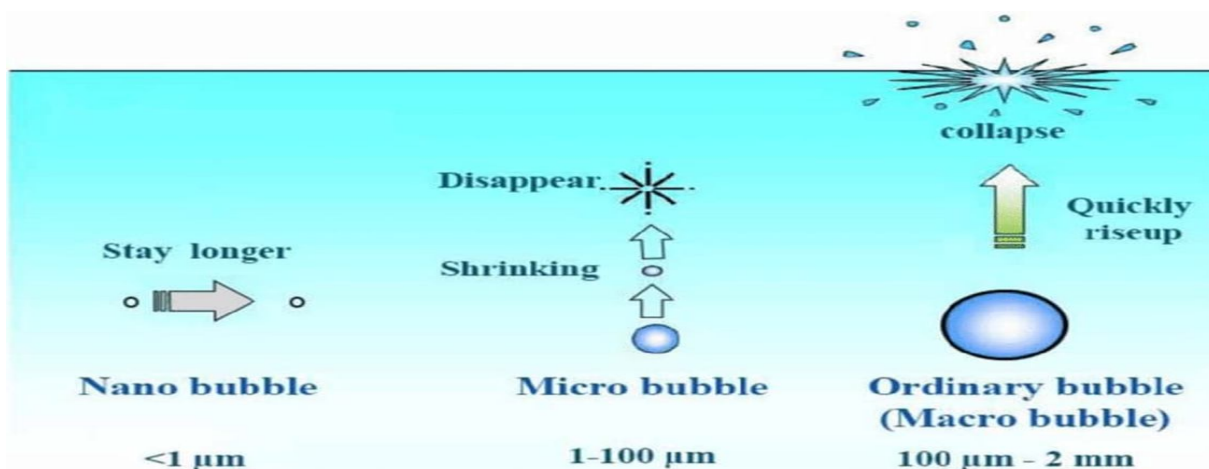


Fig.1.2: Fundamental properties of Nanobubbles

1.3 BASIC CHARACTERISTICS OF MNBS

MNBs have been highlighted due to their advantages, which include the small size, large specific surface area, long residence time in water, high mass transfer efficiency, high interface zeta potential, and the ability to generate hydroxyl radicals. These characteristics are significantly distinct over those of the traditional large bubbles. According to the principle of buoyancy, the rising speed of bubbles in water declines with the decrease of the bubble sizes. Compared with ordinary bubbles, MNBs themselves have smaller volume to bear less buoyancy and stronger surface which cause MNBs not to collapse easily. Studies have showed the rising speed of MNBs with size less than $1\mu\text{m}$ is much slower than that of Brownian motion, consequently MNBs appear to be stable in water during a long time. Generally, the mass transfer rate of a gas largely depends on the mass transfer area of the gas-liquid phases, so that of MNBs is much higher. The MNBs will undergo self-pressurization and dissolution, which can make the gas dissolution rate in water reach a supersaturated state, further improve the gas-liquid mass transfer efficiency. The combination of ions adsorption on the surface of bubbles and the creation of counter ions on the inner surface causes high interface zeta potential of MNBs, which is similar to colloid particles. In most cases, due to the difference in enthalpy of hydration between OH^- ions (-446.8kJ/mol) and H^+ ions (-1104kJ/mol), the OH^- groups are tending to adsorb at the interface of MNBs and dominate, resulting in a

negative charge on the surface of MNBs. In pure water, the Zeta potentials of air MNBs, nitrogen MNBs, oxygen MNB are -45mV , -37mV , and -40mV , respectively. The Zeta potential of MNBs is not only affected by the gas source, but also related to the characteristics of chemical reagent solution. After adding 0.001M dimethyldioctadecylammonium bromide, the Zeta potential of air MNBs changes from -22mV to 38mV . Moreover, the collapse of MNBs in the absence of external stimuli could generate hydroxyl radicals, which has been experimentally demonstrated through electron spin resonance spectroscopy. At the moment when the gas-liquid interface disappears by bubble collapsing, the extremely high concentration of charged ions accumulated on the interface through the process of MNBs self-pressurizing to dissolve will instantly release the chemical energy, which in turn releases hydroxyl radicals. The amount of hydroxyl radicals generated by collapsing MNBs is related to the type of bubbles and the pH values of solutions. Generally, oxygen MNBs are more inclined to the formation of hydroxyl radicals

1.4 METHOD FOR GENERATING MNBS

1.4.1 Pressurized dissolved gas release method

The main principle of the pressurized dissolved gas release method is to change the gas pressure. Under pressurized conditions, the air is dissolved in water to form an air supersaturated state, then the air is suddenly decompressed to precipitate out and released into the water as fine bubbles. Moreover, the decompression method can also prepare MNBs by performing a short-time pumping treatment on the aqueous solution. However, there are existing shortcomings of discontinuity of the gas dissolution and releasing processes and low efficiency of generating MNBs. To compensate for these defects, a method of generating MNBs by air flotation pump was later created, which is a combination of impeller gas diffusion technology and pressurized dissolved gas release method. Compared with the former, the MNB generation rate is higher and the bubble size is smaller.

1.4.2 Dispersed air method

The main principle of the dispersed air method is to use various methods such as hydraulic shear, high-speed swirling, jet flow, microporous structure to form shearing forces and create an extreme condition under which air is repeatedly sheared and broken to mix with water to generate a large amount of MNBs. The bubble dispersion parameters of the air NBs generated in a high-rate hydrodynamic cavitation tube, which showed NBs with average diameter of 220-280nm and concentration of 6.4×10^8 NBs mL⁻¹ when the gas-liquid volume ratio was 30%.

1.4.3 Electrochemical method

The electrochemical method can not only directly generate bulk MNBs in an aqueous solution, but also use a conductive substrate as an electrode to generate interface MNBs on its surface. The number and size of interfacial MNBs generated by electrolysis can be controlled by the magnitude of the applied voltage and the electrolysis time. Yang et al electrolyzed water to generate MNBs on the surface of highly oriented pyrolytic graphite(HOPG). When HOPG surface acted as a negative (positive) electrode, hydrogen (oxygen) MNBs were produced. Moreover, the yield of hydrogen MNBs was almost twice that of oxygen MNBs.

1.4.4 Ultrasonic cavitation

Ultrasonic cavitation is a process in which high-energy nuclei generated by ultrasonic energy grow uniformly in solution or heterogeneously on a hydrophobic surface and continuously accumulate sonic energy. When the energy reaches a certain threshold, the cavitation bubbles rapidly shrink and rupture. The effective diameter of the generated bubbles is related to the ultrasonic power and the sonication time. Vibra-Cell sonicator was used to sonicate the solution to produce MNBs with an effective diameter of 750-800nm, which increased with the increase of ultrasonic power and processing time. The efficiency of generating MNBs by ultrasonic cavitation is not high and the size of the bubbles increases significantly due to the evaporation of

volatile components as the ultrasonic treatment continues, which need to be further improved.

1.4.5 Solution replacement method

The solution replacement method requires a substrate and two solutions with different gas solubility can be mutually soluble. When a solution with high gas solubility is replaced with a solution with low gas solubility, excess gas will be deposited on the substrate surface to form MNBs. The commonly used method is ethanol-water exchange. Hu Jun et al used this method to successfully generate MNBs with overage diameter range of 100-200 nm and the concentration of 4×10^8 per milliliter which were stable for more than 4.5 hours, under the optimal conditions of ethanol/water ratio of 1:12 and experiment temperature of 35 °C. In addition, other technical methods such as high temperature, chemical reactions, photo/chemical catalysis and micro-pipes are also used to generate MNBs. Among them, the micro-pipe technology uses a micro-air pump to inject a trace amount of gas into a liquid through a micro-pipe, forming MBs in the liquid. The size of MBs is depended on the pressure and flow of the micro-pump.

1.5 MNBS APPLICATION IN WATER TREATMENT

Literature shows that MNBs have been useful in methods of water treatment, aeration, disinfection, and flotation. According to studies, the basic areas of MNBs applications in water treatment are to reduce the size of the system structures, operating time, the operating costs of processing plants, and increasing efficiency in eliminating water pollutants.

1.5.1 Aeration process

Aeration is the process of introducing or penetrating oxygen into the water substance. In water-treatment, aeration has an important role in the supply of oxygen, which is an essential element for biochemical substrate reactions and aquatic life. Numerous studies are carried out dealing with the impact of aeration processes on

wastewater and biological water treatment, and groundwater recovery. One of the key objectives of many studies was to enhance the efficiency of the factors that affect the speed of mass transfer. In common aerobic systems, dissolved oxygen is an important feature of tackling such inefficiency. In such systems, the mass transmission amount of oxygen is very important as most of the contact equipment use diffusers or mechanical aerators that require huge maintenance costs and electrical input. Therefore, studies focus more on the optimization of conventional bubbles and aerator design to improve the mass transfer aeration. However, research on the use of high mass transfer of bubbles is not well established on an industrial scale. Weber described the characteristics of the transfer rate of gas-liquid mass using MBs for aeration in the aesthete-reactors and concluded that MBs aeration is better suited to bioreactors. He further Studied the effect of MBs aeration on *Trichoderma reesei*'s fermentation (a filamentous fungus and mesophilic), which is dependent on the limited rate of oxygen mass-transmission. His study showed that the concentration of dissolved oxygen was higher than the concentration of less agitation rate due to the use of MBs aeration. Further, the concentration of cellular mass increased swiftly during the rapid growth phase, with an increase from 0.1 to 0.18 g/ LH compared to conventional bubbling. Liu reported that using NBs aerated water, the germination of the seed was improved compared to ordinary water. Likewise, Park studied the growth of lettuce (*Lactuca sativa*) by using MBs aeration and found that the dry and fresh bulks of appropriately aerated MBs lettuce were 1.7 and 2.1 times greater than the macro bubbles aeration. In these studies, the researchers hypothesized that higher germination and growth rates were associated with the specific high surface area of MNBs and the more attraction capability of positive ions. Besides, oxygen MNBs have 126 times more mass transfer efficiency, three times larger amount of dissolved oxygen (DO) compared to air micro NBs. Increased mass transmission in the bubble interface, further increases the efficiency of oxygen transmission and lead to longer stagnation of MBs in the water. In the wastewater treatment with the use of MNBs, the researcher conducted a study on the use of NBs for the degradation of aerobic waste. The results showed that the rate of use of oxygen and the volume transfer rate in the synthetic aerated NBs treatment

plants was almost twice as high as in the conventional air bubble. The degradation time of organic waste production in NBs aerated units was less than half compared to the conventional systems. Lastly, the decay and growth rate in NBs aerated unit was also much faster than the conventional system. Due to such properties, there is further need for experimental studies in this area.

1.5.2 Floatation process

The floatation has also been a major separation process in the area of water purification. The most specific substances that need to be removed from floatation are dust, chemicals, organic matter, metal ions, and oils. The efficiency of the separation process is closely linked with the size of bubbles, for instance, Dockko discussed the probability of improving the floatation efficiency, by primarily changing the characteristics of the bubbles, i.e., the size of the surface, and particles properties. In flotation, NBs and MBs are commonly used to remove pollutants from the water with greater efficiency. A subsequent number of experimental studies has evident the efficiency of this method in terms of collecting bubbles particles. Ahmed found that the speed of floatation was highly dependent on the size of the bubble as speed increased to one hundred times with the reduction of bubble size from 655 to 75 μm . Besides, indicated that the reduction in the size of the bubble in flotation is strongly correlated with an increased possibility of the tiny particles colliding with the small bubbles, which consequently lead to an increase in separation efficiency. In addition to particle sizes and small bubbles, surface charges also have a significant role in flotation. Positively charged MBs are expected to effectively isolate algae from the water, with a rate of 90% elimination of cell and 92% reduction in chlorophyll. Concerning organic substances, i.e., dissolved and organic carbon and aliphatic or aromatic mixtures, the MBs could achieve an elimination rate of more than 30%. It is found that NBs flotation (negatively charged) is a cost-effective process for the mechanical and chemical treatment of wastewater. MNBs experiments recorded a 40% increase in the efficiency of wastewater treatment, with about 95% removal of

solid wastes and silica. Besides, the cost and performance of flotation technology using NBs are significantly lower than in normal processes.

1.5.3 Disinfection process

Pollutants' oxidation and Pathogens' disinfection using ozone is a promising method for purifying wastewater. Studies show that gas bubbles of ozone due to their powerful disinfection ability successfully treat the water even with short contact time and low concentration. The effectiveness of this method has frequently increased its application for chemical resistance spore-forming bacteria (i.e., *Cryptosporidium parvum* and *Bacillus subtilis*). Further, MBs make this process more efficient, as the kinetic disinfection demonstrate a quicker decrease rate of *E. Coli* (bacteria type) (99% reduction), with a relatively small water tank and a lesser amount of ozone (for applying MBs) than the normal ozone disinfection process. Another experiment to stop the multiplication of *E. coli* resulted in a 75% reduction within three minutes using 490 W/L energy. Similarly, hydrodynamic cavitation results from various experiments proved the efficiency of such a non-reagent method like MNBs for water disinfection. Studies further showed that MBs eliminate the *Bacillus subtilis*, and results in higher log reduction (e.g., Reducing by five balls by 140 mg/l, reducing by 1.6 logs by 110 mg/l and reducing by 0.3 logs by 40 mg/L in a period of two minutes. Further experiments on the bacterial deactivation showed that the small-sized bubbles' burst force determined the efficiency of water disinfection.

1.6 ZETA POTENTIAL OF MNBS

Zeta potential is a physical characteristic used to measure the magnitude of the attraction between particles and bubbles or electrostatic repulsion. It is an important property that determines the longevity of MNB in a colloidal system. For the calculation of zeta potential, Smulochowski equation is used. Generally, MBs and NBs have a negative charge in the pH range of 2–12, depending on the kind of gas introduced, the zeta potential ranges between 50 to 40 mV and 30 to 20 mV at a

neutral pH. The negative zeta potential value is determined by the excess of hydroxyl ions (OH⁻) relative to hydrogen ions (H⁺) at the gas water interface. The charging mechanism of NBs is also associated with the preferential adsorption of hydroxyl ions in the electrolytic solution. Further, the stability of the NBs is highly dependent on hydrogen bonding at the water-gas interface, due to which NB has an impermeable, kinetically stable surface making it more diffusive resistant.

1.7 APPLICATION OF MNBS IN VARIOUS SECTORS

During recent years, due to the promising features of MNB, its application has been extended to various fields such as agriculture, medical, industry, aquaculture and domestic use. Overview of the application of MNBs technology in various fields.

Due to unique characteristics, micro-nano bubbles have attracted more and more attention in recent years. Until now, the mechanisms of MNBs generation, i.e., the generation of bubbles that displace air, creating bubbles that form the air, and producing bubbles using electrolysis have been studied.

The use of MNBs generators in mineral buoyancy, water treatment, reducing the resistance of ships, drug administration, and thermal jet printing are widely observed. However, there are certain areas where the trends of MNBs application seem more promising.

For instance, due to the enhanced time-cost efficiency and less chemical consumption, the application of MNB has great potential in environmental sustainability in addition to water treatment.

The distinctive properties such as higher mass transfer rate, collision efficiency, lower rising velocity, customized surface charge, and radical generation give MNBs a more promising role in future techniques of water treatment such as disinfection and floatation. In such treatment, high time-cost efficiency is predicted in terms of higher organic pollutants separation, floatation, aeration efficiency for biological treatments, and advanced oxidation using OH radicals.

The chemical-free radical generation property has vast potential in ozone-based MNB uses for the oxidation process. Further, the higher bursting energy of MNBs and higher aeration efficiency also has subsequent potential in terms of reducing membrane fouling and sludge formation in membrane bio-reactors. Besides, future research on MNBs technology may also focus on the optimization and automation of MNB generators to customize the MNBs generation mechanism in various sectors, including industry and agriculture. For instance, the improved smart technologies-based automation and control may facilitate the precise application of MNBs-based water treatment in agriculture and fulfill the growing demand for water treatment at various scales.

Lastly, despite the vast potential of MNBs as smart, efficient, and cost-effective treatment technology, its application is still limited to the laboratory. Hence future research and project need more focuses on its development and application at the agricultural and industrial scale.

1.7.1 Agriculture

MNBs treated water in agriculture improves the soil's physiological and biological conditions by encouraging aerobic microorganisms, which improves soil particle structure, water-absorption and oxygen dissolution, levels of the rhizosphere, microbial species and phosphate and urease, which positively impact plant growth.

NB water reduces CH₄ emission and arsenic dissolution through an oxidative shift of the redox conditions in the flooded soil. MNB accelerates the metabolism in animal and plant species.

MNBs use in hydroponics solutions for cleaning and sterilization of irrigation water (ozone bubbles). The high oxygen content and permeability of MNB promotes plant root growth, enhances nutrient absorption, shortens the growth cycle and hence improves economic efficiency

MNBs application through drip kills bacteria, removes harmful substances and odors from water, and improves freshness and taste and yield of fruits and vegetables.

MNBs use for biological and weeds control (i.e., facilitate triopsidae growth, which stops the weed growth in rice fields and also decreases chemical and fertilizer usage). MNBs water improves the rate of seed germination.

1.7.2 Aquaculture and fisheries

MNBs improves blood flow and bronchial respiration of fish. MNBs reduce the lodge near the sea caused by increased environmental pressure (restore the poor oxygen condition at the bottom by fresh air and improves decomposition of organic matter, essential for marine life.

MNB treated water application on aquatic plants and fisheries significantly increase the growth by improving nutrient uptake

1.7.3 Cellular biological

MNBs are used in fermentation. Medical MNBs are used to diagnose the tumors in the human body by ultrasonic imaging.

MNBs are used for curing cancer patients in different forms and treatment methods.

MNBs are used in the dentistry treatment and the conditions that affect the teeth and gums (insertion, repairing, and extraction of teeth. MNBs are used for the detection of malaria. MNBs are used in genetics (drug-oxygen-gene delivery nexus).

1.7.4 Industry Energy systems

MNB eliminate mixed oil and carbon from water and provide economic benefits for water reuse (dissolving air with polyelectrolytes with hydrogen MNBs)

MNBs are used in solar energy (solar vapor nanobubbles generation as a result of the complex interaction of several phenomena that occur at the nanoscale and can be used in a variety of applications, i.e., solar steam energy NBs generation).

1.7.5 Domestic uses

Oxygen produced by ozone decomposition generates such ions that can oxidize pollutants in drinking water. MNBs are used in the laundry and tableware. Its use in swimming pools, shower, and bathtubs for strong antioxidant effects have subsequent health benefits such as removal of aging skin, deep-rooted dust particles, bacteria, and chemical residue, which accelerate skin metabolism, and blood circulation.

MNBs is a promising technology, and its application has spread significantly over the last decade to a wider range of sectors covering energy, environment, industry, agriculture, and aquaculture. This review article mainly presents the existing context and the state of research on MNBs use in various areas of water treatment applications such as in flotation technology, disinfection, aeration, and advanced oxidation.

The application of MNBs technology, especially in agriculture and aquaculture, is highly promising with abundant opportunities. Although the current status of research and practice is making significant progress gradually, the development is steady. For instance, most of the literature available on

MNBs application is based on water-related applications in major primary sectors such as agriculture, aquaculture; however, expansion is needed for sectors such as medical science.

Further literature shows ambiguity in terms of fundamental properties, such as stability of bulk NBs, as it has not been well explained until now. Only a few experimental studies deal with the stability and longevity of NBs, with no considerable consensus.

The studies have yet to decide whether properties such as separation, stability are following scientific guidelines (classical thermodynamic principles). Although progress has been made and several hypotheses have been proposed explaining the long-term stability of NBs, none of them describe these experimental observations. Lastly, this study seeks further investigation regarding the improvements in performance

techniques, bubble growth, and size under various physical and chemical conditions, bubble generation methods, and automated optimization.

1.8 BUBBLE STABILITY IN THE ULTRA SONICATION FIELD

It has been found that bubbles vibrate once exposed to supersonic waves. to boot, the vibration of the bubble seems otherwise supported by the acoustic pressure applied. The supersonic device is intended with the flexibility to regulate the acoustic pressure by adjusting the mechanical index (MI). this can be done by dividing the height rare half pressure of the supersonic wave by the root of the supersonic center frequency. Living tissues manufacture linear vibrations below the associate degree supersonic field. once the MI is low, the bubble causes a linear vibration with an identical degree of contraction and enlargement. in a very slightly higher MI, they cause a nonlinear vibration, wherever the microbubbles expand quite they contract. This nonlinear vibration represents proof that's furthermore, stable cavitation happens once bubbles cause nonlinear vibration, whereas mechanical phenomenon cavitation happens once the bubbles are destroyed. once cavitation happens, an action within the close cell structure takes place. to boot, the gas within the bubble is eluted, and a robust wave, shear force, and micro-jet square measure generated. These changes embrace the transformation or degradation of vesicles which will cause changes in macromolecule cell membranes, even while not mechanical phenomenon cavitation. Additionally, a number of the supersonic energy is born-again into thermal energy and absorbed by the encompassing tissues and their temperature will increase. The tissues that absorb heat actively exchange materials, thereby increasing the delivery potency of gases or medicine within the bubble. once a bubble is exposed to supersonic waves to cause cavitation, the prevalence of stable or mechanical phenomenon cavitation is influenced by many factors, together with the characteristics of the supersonic wave, the dimensions, and composition of the bubble, and also the close surroundings. many models are developed to predict the development of one bubble. The Rayleigh–Plesset equation, which expresses the

bubble behavior in an incompressible fluid, is usually wont to develop these. Bubbles within the supersonic field will cause cavitation. Cavitation is littered with encompassing surroundings, like acoustic pressure, center frequency, pulse length, and characteristics of the medium. Acoustic pressure refers to the modification in pressure generated by sound waves passing through a medium. Acoustic pressure takes the shape of undulation in a very time–pressure relationship, and there are peaks and lows. the bottom purpose of the acoustic pressure is named the peak-rare factional pressure, and this can be associated with the fragmentation threshold since the bubble expands. Mainly, the fragmentation threshold suggests that the minimum acoustic pressure for mechanical phenomenon cavitation occurs. additionally, once applying continuous ultrasound, the fragmentation threshold will increase because the frequency will increase. once periodical ultrasound is applied, the edge decreases because the ultrasound application time will increase. this can be as a result of bubbles stabilize throughout the off-time interval of periodical ultrasound. Compared to a bubble while not a shell, a bubble with a shell is twenty times tougher at the interface. Thus, the frequency of supersonic waves for cavitation is additionally higher. to boot, the thicker the gastropod, the upper the frequency of supersonic waves needed for cavitation. The frequency of the supersonic wave needed additionally varies per the composition of the shell as a result of the movement of the gastropod is influenced by the physical phenomenon and also the volume consistency constant State of the nanobubbles within the supersonic field. once the bubble enters the supersonic field, it oscillates. If frequency overcomes the edge, cavitation happens. Moreover, stable cavitation happens once bubbles cause nonlinear vibration, whereas mechanical phenomenon cavitation happens once the bubbles square measure destroyed. once cavitation happens, an action within the close cell structure takes place. to boot, the gas within the bubble is eluted, and a robust wave, shear force, and micro-jet square measure generated. These changes embrace the transformation or degradation of vesicles which will cause changes in macromolecule cell membranes, even while not mechanical phenomenon cavitation. to boot, a number of the supersonic energy is born-again into thermal energy and absorbed by the encompassing tissues and their temperature will increase. The

tissues that absorb heat actively exchange materials, thereby increasing the delivery potency of gases or medicine within the bubble. once a bubble is exposed to supersonic waves to cause cavitation, the prevalence of stable or mechanical phenomenon cavitation is influenced by many factors, together with the characteristics of the supersonic wave, the dimensions, and composition of the bubble, and also the close surroundings. many models are developed to predict the development of one bubble. The Rayleigh–Plesset equation, which expresses the bubble behavior in associate degree incompressible fluid, is usually wont to develop these. Bubbles within the supersonic field will cause cavitation. Cavitation is littered with encompassing surroundings, like acoustic pressure, center frequency, pulse length, and characteristics of the medium. Acoustic pressure refers to the modification in pressure generated by sound waves passing through a medium. Acoustic pressure takes the shape of undulation in a very time–pressure relationship, and there are peaks and lows. the bottom purpose of the acoustic pressure is named the peak-rare factional pressure, and this can be associated with the fragmentation threshold since the bubble expands. Mainly, the fragmentation threshold suggests that the minimum acoustic pressure for mechanical phenomenon cavitation occurs. additionally, once applying continuous ultrasound, the fragmentation threshold will increase because the frequency will increase. once periodical ultrasound is applied

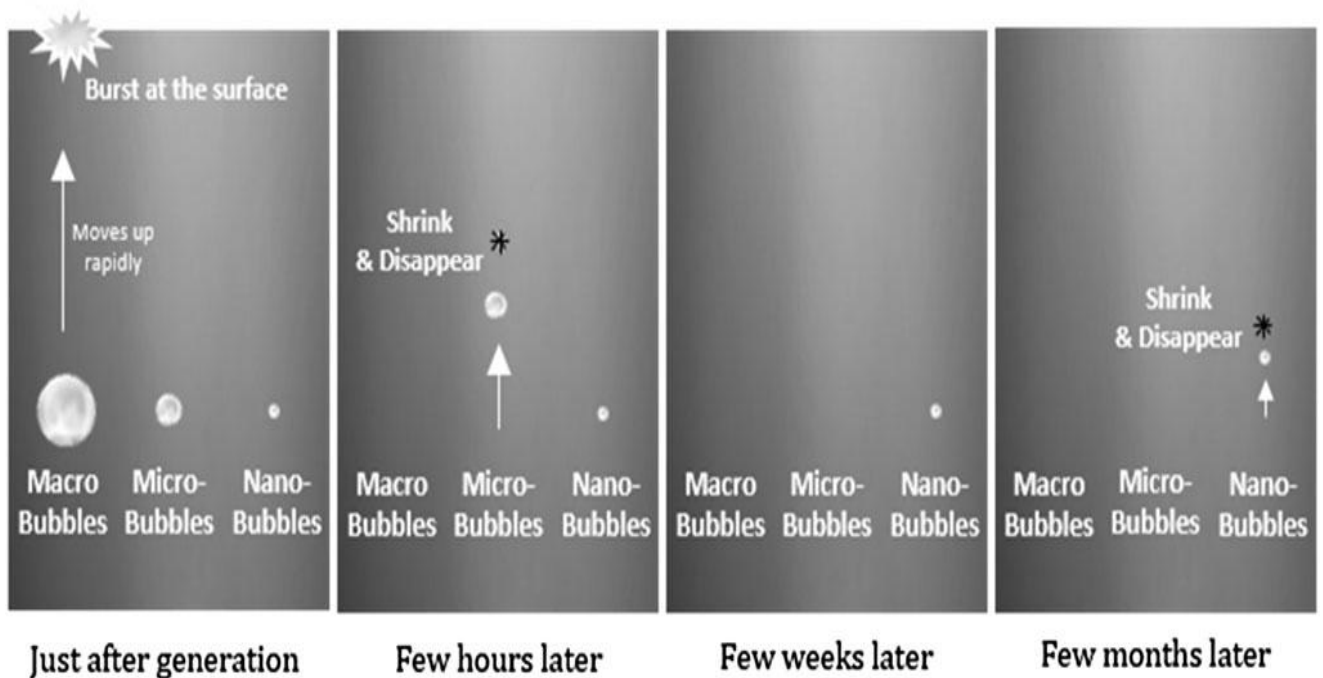


Fig 1.3: Stability of Bubbles

1.9 PRESENT STUDY

Micro- and nanobubbles ozonation in removal of organic and inorganic pollutants, decolorization, and disinfection in water and wastewater. The intense hydroxyl radical generation enables effective removal of the pollutants in a wide range of pH and the highly improved ozone utilization related to efficient mass transfer make the technology economical. Since the free radical is generated in the absence of chemicals and the loss of ozone is minimal, wider application of this environmental friendly technology of refractory and NOM mineralization in water systems is promising. Because ozone is a strong oxidant, it can be hazardous to handle. Moreover, leakage, corrosion and excess ozone gas treatment, which may lead to frequent operation and maintenance of ozone contact tanks and pipping, are relatively low due to high ozone utilization efficiency of ozone MNBs compared to the conventional systems. The potential risks of ozone promoting corrosion to steel or other engineering alloys, depend on concentration of ozone used. Generally,

corrosion may result at higher ozone concentration than the use of MNBs, by which efficient utilization limits ozone concentration, attributes to decrease of the system susceptibility to corrosion. At lower concentration a thin protective layer may even form on the metal surface.

Due to the scarcity of water resources and the harmful effects of sewage on water bodies, water purification becomes an important issue. The application of ultrasonic waves is a novel technique developed for water purification. This technology works as an advanced method of oxidation, contributing to the elimination of various types of contaminants. The basic principle of ultrasound is based on the destruction of both bacterial cells and difficult to degrade organics. A brief overview of water purification methods, application of ultrasound, ultrasound waves theory and the benefits and drawbacks of using ultrasound waves in water purification will be discussed in this article. In addition, the role of ultrasound waves in the degradation of various organic contaminants, microbial pollutant disinfection, and other pollutants removal.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

Recently, micro-Nano bubbles (MNBs) have been widely used as a highly efficient and environmentally friendly gas-liquid phase treatment process in sewage and wastewater treatment, aquaculture agriculture, and water ecosystem restoration. In this article, the basic characteristics of MNBs with long residence time, high zeta potential at the interface, generation of hydroxyl radicals, and high mass transfer efficiency were introduced. Firstly, the methods of generating MNBs including hydraulic cavitation, particle cavitation, sonic explanation, electrochemical cavitation was emphasized. Then, the application status of MNBs in water oxygenation, pollutant degradation, and membrane cleaning were discussed. These reviews are expected to provide guidance for the theoretical research and practical application of MNBs.

2.1.1 Studies on Sound theory

The sound can be represented as a mechanical energy transmitted in gas, liquid or solid form by pressurized waves. This general definition includes all sound forms, including audible sound, seismic (infrasound) low-frequency waves, and ultrasound. Ultrasound is a cyclic sound stress with a frequency greater than the human hearing upper limit. It is about 20 kilohertz (20,000 hertz) . In a transmission medium such as a gas, liquid or solid, sound can be represented as mechanical energy transmitted by pressure waves. Sound can therefore be defined as a mechanical energy. This overall definition encompasses all forms of noise, including visible, low frequency seismic and ultrasound waves. Ultrasound is cyclic sound pressure, which reaches the upper limit of human hearing; the frequency is about 20 kilohertz. US could be generate by two main techniques, the first is called “magnetostrictive” in which electrical energy is converted to mechanical energy (or vibration) with a magnetic coil attached to vibrating piece like nickel and Terfenol-D. The second is piezoelectric technique, the electrical energy is converted to high frequency electric energy with

piezoelectric crystals attached to the vibrating piece (sonotrode, probe or horn) The majority of modern ultrasonic devices rely on piezoelectric materials transducers. These materials react with a small change in size to the application of an electric potential on opposite sides. That's the opposite of the piezoelectric effect. The crystal translates electrical energy into mechanical vibration (sound) energy when it alternates at high frequencies. High frequency sound (ultrasound) is produced at sufficiently high alternating potential. A lower frequency ultrasound can cause chemical changes for a system as a result of acoustically induced cavity. Ultrasound (US) wave application with or above a frequency of 20,000 Hz called "sonication". This frequency is above the sonic range (20 Hz to 20 kHz) at which humans are able to listen and below the mega-sonic zone (>600 kHz). The motion of the molecules in the setting in which the wave spreads is transmitted energy by US waves. Ultrasound has ranges of approximately 10 to 10 cm in successive waves of compression. The molecular dimension is not comparable. Based on this fact, the ultrasound's chemical effects cannot result from direct sound contact with molecular species.

2.1.2 Studies on Cavitation

Hammit proposed that cavitation is the formation, growth and eventual dissolution of cavities releasing enormous amounts of energy from the conversion of kinetic energy from the motion of fluids into heating of bubble contents. Through generating hydroxyl radicals and also hydrogen peroxide, it also produces heavy oxidizing conditions. Warade, Gaikwad, Sapkal, & Sapkal, 2 proposed that the chemical behavior is similar to Advanced Process Oxidation. Cavitation is a complex process that depends on the volume and structure of bubbles and cavities over a continuous time period. The pacing is in line with milliseconds. After the fluid has passed into regions that have reached critical pressure, sudden implosions in bubbles and cavities are much smaller than milliseconds in time, resulting in regional rises in pressure in several parts of the area. The pressures in the fluid can locally reach hundreds of mega-Pascal, even thousands. Gogate proposed that the hydrodynamic, electrical, acoustic, chemical, thermal and even electrostatic effects related with cavitation bubble implosions are common. Eskin&Eskin 2 proposed that Cavitation occurs if a

threshold of 0.06–0.1 MPa exceeds acoustic pressure amplitude for distilled water, and when driving frequencies of about 20 kHz are used.

2.1.3 Studies of Membrane filtration

Ng et al proposed the studies on drinking water treatment, membrane, a term that applies to a number of different processes using artificial membranes to isolate chemicals, has been recognized as the primary technology for separating pollutants from contaminated sources, thus purifying original waters. Cho, Amy, & Pellegrino, ; Nakatsuka, Nakate, & Miyano, made studies on membrane processes that play a vital role in complementing conventional water treatment systems to meet ever more rigorous drinking water requirements and maintain public trust). Lamminen, Walker, & Weaver proposed that membrane fouling is one of this technology's main drawbacks. Reducing membrane fouling and flux decline has been a critical challenge in membrane applications that can affect the efficiency of water production, membrane existence and operating costs. In recent years, Boreastudied that combining membrane processes with ultrasound (US) is a revolutionary membrane fouling control strategy that can increase membrane activity. During membrane filtration, the concept of using US relies primarily on US cavitation effect. Like any sound wave, ultrasound is propagated through a sequence of waves of compression and rarefaction (decompression) caused by the medium's molecules. The rarefaction process will surpass the attractive forces of the liquid molecules at a sufficiently high energy, and cavitation bubbles (empty, gas-and/or vapor-filled bubbles) are formed. As these bubbles form and burst under different pressures, they release energy and cause vibrations that loosen particles on the membrane surface without compromising the efficiency of the procedure. Lamminen in 2004 showed that by splitting the polarization concentration and cake layer on the membrane surface, it increases the flux. The effects of speed, power strength, feed properties, membrane properties, cross-flow rate, temperature and pressure are determined by several parameters. Consideration should be given to the integrity of the membrane during ultrasound treatment. Ultrasonically enhanced membrane filtration is still not commonly advertised. Kyllonen et al. found the main reasons for a break-through

prevention are the growth of stagnation of membrane filtration transducer technology and membrane erosion control. Kobayashi, Chai, and Fujii (1999) found that the US increased permeation by increasing the coefficient of mass transfer of water through ceramic membrane microfiltration as well as organic membrane ultrafiltration. Kobayashi; Muthukumaran proposed that US irradiation studies have established prevention of concentration polarization and membrane fouling due to stripping of the cake layer, producing a less compressible fouling sheet, and reducing concentration of solute close to the membrane surface American cleaning processes are divided into four distinct pathways: acoustic streaming, microstreaming, microstreaming, and micro jets. The collapse of cavitation bubbles does not require just acoustic streaming. Ultrasonic waves cause massive movement of water to and from the surface of the membrane, producing forces to push and pull away from the surface. Micro streaming happens as bubbles oscillate in size and with an effective range of bubble diameter produce significant shear forces. The phenomenon of micro streamers is described as the cavitation bubbles that move in ribbon-like paths as these bubbles fly vigorously around the surface of the membrane. When translating to antinodes, they appear to coalesce and scour off particles. Micro jets occur when two asymmetric cavitation bubbles collapse simultaneously or only one bubble collapses near a solid interface and produces a powerful jet of water that scores particles away from the surface of the membrane. Several scientists have demonstrated the efficacy of US-associated membrane cleaning to increase permeates flux and extend the lifetime of the membrane. The US recovered flux with forward flushing on a 0.2 mm nylon membrane filled with an effluent recorded by Li, Sanderson, and Jacobs (2002) from the Kraft paper factory. Fouled membrane supported by US backwashing is more rigorous than traditional backwashing is founded by Matsumoto, Miwa, Nakao, & Kimura, 1996. In some studies, ultrasound damage on the membrane surface has been observed by Juang & Lin on 2004. In other research, the membranes were even damaged by repeated use of ultrasound shown by Borea et al., 2018; Lamminen et al., 2004. Use of the sporadic U.S. procedure will likely be less energized than continuing US radiation and U.S. pulsed layers of bovine serum albumin (BSA) from a cross-flow mf are effectively removed is proposed by Yuk & Youm, 2003.

2.1.4 Studies of ultrasound for turbidity and total suspended solid reduction

Turbidity is a major physical feature of air. EPA on 2014 found that the presence of scattered hanging solids such as clay, silt, algae and other microorganisms, organic material and minute particle materials can be detected. A variety of methods have been used in the water treatment process for reducing turbidity, Total Suspended Solid (TSS) filtration and slow-filtration, ultrafiltration and coagulation/flocculation. American procedure for turbidity reduction (TSS) and advanced oxidation treatment has been extensively studied by Manson & Lorimer, 2002. The US efficiency may improve by increasing turbidity or suspended solids compared to conventional methods that are negatively affected by the suspension of effluent solids. Mutiarani and Trisnobudi (2009) studied the use of ultrasound in TSS elimination and found that removal efficiency in the different conditions was extremely high. At a frequency of 28 kHz, 60 Watts of power, the most turbidity reduction (76%) was achieved. At 27,2 kHz at 30 seconds, water turbidity decrease 4 times over (39 NTU) at 27,2 kHz (Stefan & Balan, 2011). The results show that TSD reduction was increased at 30 min ultrasound rate, but was unpredictability from 60 to 120 min of irradiation at all power densities for all energy densities. Chua, Abdullatif, and Ibrahim (2009) have studied the impact of power density on TSS reduction. The efficiency was 0,024 W/cm³ , 120 min with 84% of output and 60% with a minimum percentage reduction at 0,06 W/cm³ for 60 min. The most effectual result was reducing turbidity of raw water by a precursor to coagulation from 10,3 NTU to 1,48 NTU and by 15 s ultrasonic irradiation at 40 kHz 60 W were examined by Liang, Nan, & He, 2009.

2.1.5 Studies of ultrasound in organic pollutants degradation

POPs are the specific environment polluting group, through high toxicity, persistence and bioaccumulationability are examined by Ozonk, 2012. Persistent organic pollutant. Several research studies have demonstrated applications for the decomposition of different biological pollutants, such as chlorinated hydrocarbon, pesticides, phenol, explosives, such as TNT and esters. It takes minutes to hours to

complete degradation examined by Kot-Wasik 2003. Psillakis et al. (2004) examined the degradation of polyaromatic hydrocarbons (naphthalenic and acenaphthylene) by water using ultrasonic machines at initial concentrations of 150, 300 and 450 µg/l at 20 and 40 °C, applied energy of 45, 75 and 150 W and ultrasound frequencies of 24 and 80 °C and found that a complete degradation of water was possible at initial concentrations of 150, 300 and 450 mg/l. Manousaki, Psillakis, Kalogerakis, and Mantzavinos (2004) investigated the decomposition from ultrasound effects of sodium dodecylbenzenesulfonate (SDBS) under different experimental conditions. Due to the increased temperature, starting solvent concentration and decreasing power and frequency the SDBS degradation has been shown. In addition, the work into the transformation mechanism showed that SDBS decomposed primarily at the bubble liquid interface and, to a lesser degree, in the liquid bulk by radical reactions. The municipal wastewater phenol is one of the most concentrated toxins investigated by Entezari, 2003. Their presence in soil, rivers and drinking water attracts attention from the general public. Guo and Feng (2008) investigated the evaluation of ultrasonic bisphenol A (BPA) degradation in aqueous solution; suggested that BPA had been degraded by hydroxyl radical advanced oxidation with a frequency of 20 kHz in the presence of CCl₄. Torres (2008) have studied the removal effects of bisphenol A (BPA) on ultrasonic action under different experimental conditions. They showed that the best performance for 118 µmol/L BPA was 300 kHz, 80 W for 90 min, and oxygen as a saturated gas for this solution. Hydroxyl radical reaction is also the main mechanism for phenol removal. Application of a hybrid advanced oxidation technique (son electro-Fenton process) for the degradation of herbicides from aqueous solutions was studied by Oturan et al. (2008). They suggested that the decomposition of 4, 6-dinitro-o-cresol (DNOC) and 2, 4-dichlorophenoxyacetic acid (2, 4-D) herbicides by sonoelectro-Fenton process is due to the following contributions: (i) enhanced mass transfer rate of reactants towards cathode, (ii) additional generation of OH by sonolysis, and (iii) pyrolysis of organics due to cavitation generated by ultrasound irradiation.

2.1.6 Studies of ultrasound for water disinfection process

The decontamination of water is critical to the destruction of humanly ill microorganisms. Chlorination, chlorinated dioxide, chloramines, ozone and ultraviolet light examined by Pozos, Scow, & Wuertz, 2004 form part of the main water treatment process. The main forms of chlorine commonly used in the disinfection process are chlorine gas and its derivatives sodium hypo-chlorite (NaClO), or calcium hypo-chlorite ($\text{Ca}(\text{ClO})_2$) studied by Windward, Avery, Stephenson, & Jefferson, 2008. All forms of chloric are, however, highly corrosive and poisonous to the foot. DBPs are a serious problem caused by the reaction of the organic matter and the disinfectant, which is the result of the disinfection of the organic material proposed by Liu & Chiou, 2005. Many variables that influence the species and concentrations of DBPs; the form and concentration of the disinfectants used, the size, temperature and pH and when the disinfectant is used in the water treatment system formed by Petrier, Jiang, & Lamy, 1998. The release into water of these toxic DBPs produces major environmental concerns. In this regard, a large number of studies have been carried out to remove the limitation by using the ultrasound (US) method, which constitutes a fairly advanced technique for traditional processing technologies investigated by Dhermendra, Tiwari, & Behari, 2008; Khan, Shen, & Lin, 2006; Kumar et al., 2015. This drawback emphasized the need to explore alternative and new treatment technologies formed by Gopal, Tripathy, Bersillon, & Dubey, 2007. In the late 20s, Harvey and Loomis (1928) published their first report on the use of ultrasound as a disinfectant. In the early to mid-1970s, numerous researchers explored the use of ultrasound as a disinfectant because of its ability to decrease bacterial spore heat resistance proposed Burleson, Murray, & Pollard, 1975; Dahi, 1976. Ultrasound disinfection is now well documented to be related to cavitation phenomena insisted by Zou & Tang, 2019. Many scientists studied the use of US water treatment techniques, alone or joined with other procedures for disinfection. US disinfection procedure has also been extensively examined for their parameters.

2.1.7 Ultrasound and chemicals synergistic effect.

Ultrasound has also been used in combination with other advanced oxidation processes was proposed by Phull in 1997 found a synergistic effect between

sonication and chlorination. *E. coli* suspended in saline solution and raw stream water were used in their experiments. After 5 min of treatment time, the application of 1 mg L⁻¹ chlorine inactivated 43% of the bacteria in the sample stream water and sonication alone inactivated 19%. When sonication was applied followed by chlorination, 86% inactivation of bacteria was achieved. After 20 min, the combined sonicity and chlorination resulted in 100% inactivation of bacteria. The findings also showed that rising bacterial kill by 40% for a 5-min treatment period in chlorine improved the sounding energy of 12 W/cm² to 21 W/cm². Sonication accompanied by chlorination is safer than sonification, which induces a degassing effect and leads to lower concentrations of chlorine formed by Ayyildiz, Sanik, & Ileri. Sequentially combined ultrasound and chlorine dioxide were used to improve *Escherichia coli* and the inactivation of total coliforms in raw wastewater was studied by Nilsun&Bele. A simultaneous application of the ultrasonic density values of 150 or 300 W l⁻¹ and ClO₂ of 2 mg L⁻¹ reduced the number of microorganisms by around 2.3–3.5 log reduction in the number of microorganisms, while the sum of log reductions by the individual treatments were 1.4–1.9. This enhancement was attributed to the presence of high concentration of particles in raw wastewater and their influence in improving ultrasonic cavitation effects.

2.1.8 Sonication and ozonation synergistic effect.

Use ultrasound with an ozone-powerful oxidant improves water and wastewater treatment through the production of emulsion from both suspended and dispersed particles, and through the prevention of ozone bubble coalescency, thus ensuring the total oxidation bubble area was formulated by Zou & Tang, 2019. A study was conducted on the inactivation of *E. coli* when subjected to ozonation alone, simultaneous ozonation and sonication, and sonication followed by ozonation done by Von Gunter. The results showed that with the same given disinfection time, ozonation alone provided the least inactivation of *E. coli* compared to the combination of ozonation and sonication. Ultrasonic waves indicated increased microbial inactivation with ozone, and processes of chemical oxidation caused by free ozone radicals.

2.1.9. Ultrasound and ultraviolet synergistic effect.

Ultraviolet (UV) irradiation is a wave with a space between the Ray-X and visible ray 100–400 nanometer (nm) studied by U.S. EPA, 1999. A low pressurized light (253.7 nm) or medium pressure (180–1.370 nm) for UV disinfection is used. The brightness of medium pressure lamps is much greater than that of low pressure lamps. Paleologou have investigated the application of ultrasound to improve the wastewater disinfection system as a pre-treatment phase combined with ultraviolet and have found that the US allowed the reaction time needed to complete removal of UV radiation from Total coliforms to be halved alone. The combined use of ultrasound and UV to enhance the disinfection of fecal coliform was investigated by Joyce, Mason, and Lorimer. A UV reactor with an ultrasound power density of 0.05 W/cm³ is placed within an ultrasound bath during their experiments. We found that the simultaneous use of ultrasound and UV in the UV reactor increases the overall disinfection substantially, resulting in complete inactivation in 30 minutes. A variety of experimental studies have reported synergistic effects between sonics, UV and metal ions. Their results show that, when successive and hybrid methods are used, the efficiency of bacterial inactivation was increased and the disadvantages eliminated. They also demonstrated that hybrid application of water disinfection with lower environmental risk and increasing individual drawbacks of disinfection methods could effectively occur with antibacterial column, ultrasound and UV.

2.2 SUMMARY OF LITERATURE REVIEW

Many literatures have been studied thoroughly and many results were analyzed. These results helped us in using the method effectively. The current research has many facts to understand and based on that the conclusions are incorporated.

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM OF THE PROJECT

- To attain the solution to water scarcity and harmful effect on water bodies
- To generate Nano bubble by means ultrasonic waves
- To perform various test on the sample
- To perform test on various sample

3.2 SCOPE OF THE PROJECT

Due to the scarcity of water resources and the harmful effects of sewage on water bodies, water purification becomes an important issue. The application of ultrasonic waves is a novel technique developed for water purification. This technology works as an advanced method of oxidation, contributing to the elimination of various types of contaminants. The basic principle of ultrasound is based on the destruction of both bacterial cells and difficult to degrade organics. A brief overview of water purification methods, application of ultrasound, ultrasound waves theory and the benefits and drawbacks of using ultrasound waves in water purification will be discussed in this article. In addition, the role of ultrasound waves in the degradation of various organic contaminants, microbial pollutant disinfection, and other pollutants removal

CHAPTER 4

MATERIALS AND METHODS

4.1 METHODOLOGY OF RESEARCH

After studying and reviewing the various literatures with the information and facts learnt, the clear process of methodology proposed for the research work is illustrated as follows:



Fig:4.1 Flow Chart depicting the Research Methodology

4.2 MATERIALS REQUIRED

The materials required for our research work are

- Ultrasonicator
- Air compressor
- Eliminator
- Measuring beaker

4.2.1 Ultrasonicator:

Ultrasonic generator uses [cavitation](#) bubbles induced by high frequency pressure (sound) waves to agitate a liquid. The agitation produces high forces on contaminants adhering to substrates like metals, plastics, glass, rubber, and ceramics. The bottom plate is freely vibrated due to the ultrasonic frequency. It can produce the ultrasonic power of 50 W. Ultrasonic frequencies up to 40 kHz. The tank capacity 0.6 Litre. Size of the tank 150. 85 .65 mm (L. W .H)



Fig: 4.2:. Ultrasonicator

The container was vibrated under the ultrasonic wave at a frequency of 40 kHz and the 300 W power of the generator. The temperature is set to 25 °C.

4.2.2 Air Compressor

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume. This device is a 12 V DC air compressor. It is used to generate compressed air of 150 PSI. In the methodology the role of the compressor is generate

the vapour or micro Nanobubble. It also used to sweep the impurities that settle at the bottom of the measuring beaker. The device generates the maximum ampere of 13.5amp.



Fig 4.3: Air Compressor

An air compressor of capacity 0- 5 bar was incorporated for injection of air with shearing action in the water at a constant pressure of 1.5 bar so that NBs was produced

4.2.3 Eliminator:

The eliminator is known as the converter. This device is used to convert the ac to dc voltage. The eliminator is preferable for 10-amp device. This device is helpful in the process



Fig 4.4: Eliminator

4.3 METHODS INVOLVED

4.3.1 Nanobubbles produced by the ultrasonic method

The basic principle of nanobubbles generation methods is to create a locally oversaturated state for gas to induce the nucleation of gas molecules for the next formation of nanobubbles. There is one important factor, gas saturation. The saturated concentration of gas in water is related to the pressure and a high gas concentration may not be necessary. The gas unsaturated aqueous solution at normal temperature and pressure would turn into a gas oversaturated state, and extra gas molecules might be released and aggregate into bubbles. While our method concentrating on the nucleation: ultrasonic cavitation. When the ultrasonic wave contains higher intensity than the “cavitation threshold”, tiny nuclei form internally, with their diverse behaviors in the opposite/negative pressure zone, the nuclei shrink or dilate, and if the nuclei dilate to a certain magnitude, then the gas molecules dissolved in the solution transfer into a nucleus to grow up to a nanobubbles. Based on these principles, we put a glass container (diameter 75 mm, height of water 80

mm) in the ultrasonic water which was covered by a porous membrane to separate contamination from the air but maintain the normal pressure, the container was vibrated under the ultrasonic wave at a frequency of 40 kHz and the 300 W power of the generator. The temperature is set to 25 °C. The hydrodynamic cavitation, constant temperature stirring, electrolysis, ultrasonic cavitation, oscillation of fluid, solvent-water mixing, plunger mechanism was some of the unique techniques practically in existence for the generation of NBs based on the characteristics of liquid medium and application criterions. In our experimental procedure, we used an ultrasonic sonicator combined with an air compressor for the creation of tangential force in water to be tested. The sample was first vibrated for 15 mins at isothermal conditions and the process was repeated 3-4 times for the observation of NBs. The stability, zeta potential and the size distribution of the NBs were ensured with the addition of oleic acid as a surfactant with a concentration of 0.05% by volume basis. The 300 ml of water to be tested was filled in a 500 ml beaker, kept in the sonicator and subjected to vibration for nearly 1 hour at a constant temperature of 30⁰ C. An air compressor of capacity 0- 5 bar was incorporated for injection of air with shearing action in the water at a constant pressure of 1.5 bar so that NBs was produced. The macro bubbles generated during the process moves up due to the buoyancy and collapses near the top surface of the beaker.



Fig 4.5: Ultrasonic nanobubbles generator



Fig 4.6: Titrated Samples

CHAPTER 5

RESULT AND DISCUSSION

5.1 LASER TESTING

By comparing the scattered light intensity, it is possible to differentiate between micro bubbles and nanobubbles. The refractive index for micro bubbles is smaller than water and that of nanobubbles (60 nm) is greater than water, the variation in scattered light intensity can be considered naturally. The nanobubbles in the water will scatter the light when it is passed through it. The beam of laser was passed through normal water (Fig. 5.1a) and nanobubbles water (Fig. 5.1b). A laser source was used to generate laser beam. It was observed that the laser beam width was maintained constant throughout the normal water but the beam width decreases and converges into a point due to the constant horizontal motion and high internal pressure of nanobubbles in the nanobubbles aqueous solution. The converging effect of Nano bubble water clearly shows that the presence of nanobubbles. This process is another experimental evidence for the presence of nanobubbles in water.

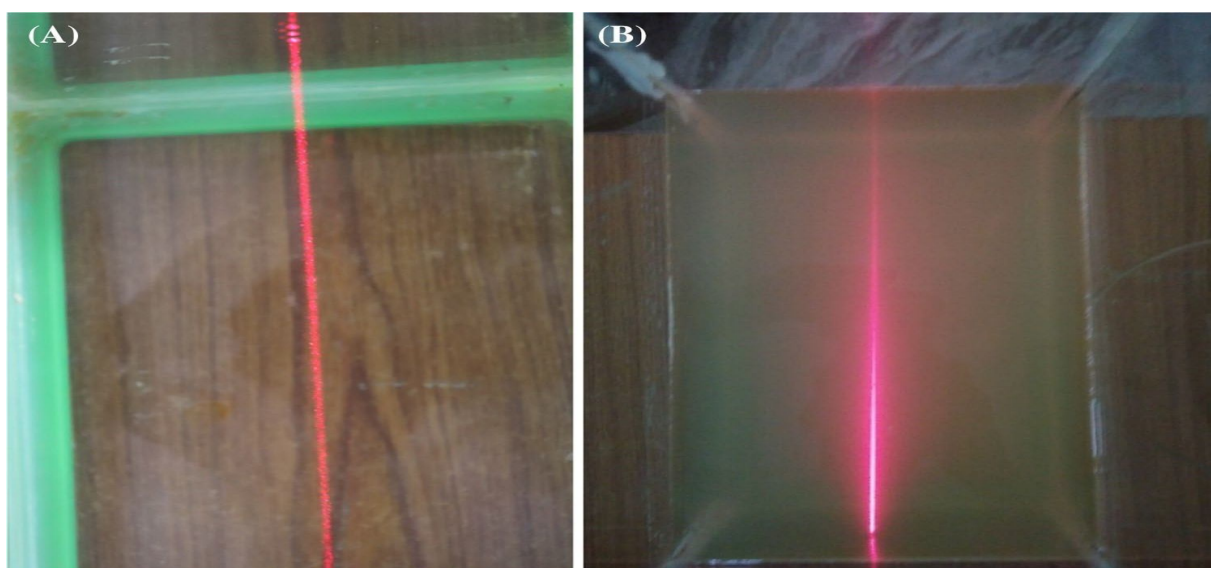


Fig: 5.1 a Laser beam passed through water without nanobubbles

b Laser beam passed through water with nanobubbles

5.2 CHEMICAL OXYGEN DEMAND (COD)

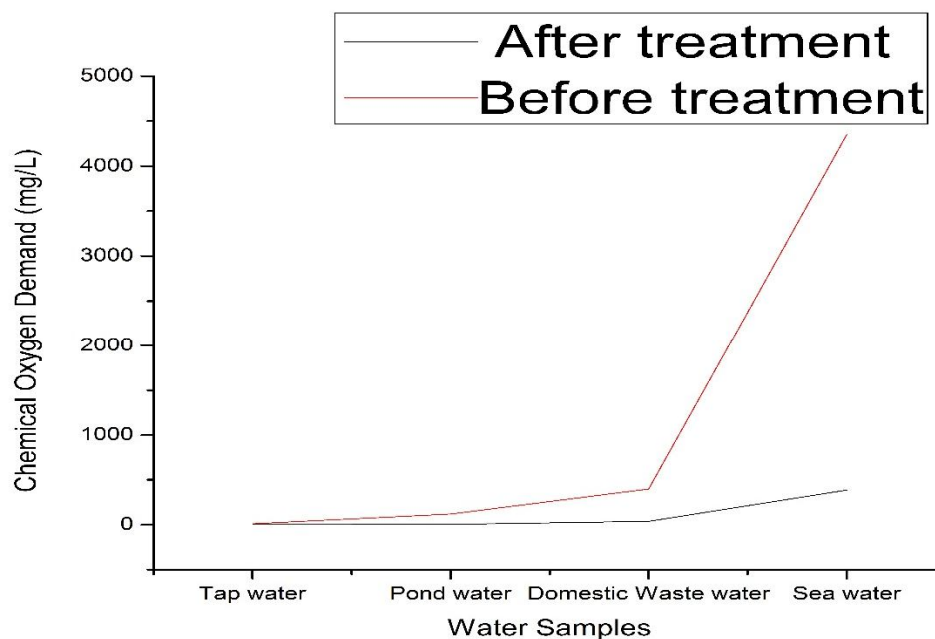


Fig 5.2: Chemical Oxygen Demand

The chemical oxygen demand (COD) specifies the oxidation behavior of organic substances present in water which in turn is a measure of normal water and waste water quality. The chemical oxygen demand and biochemical oxygen demand (BOD) are the measure of level of pollutants present in water. From the previous research studies, it was confirmed that many commercially available COD analyzers incorporated in the measurement of COD. COD is the deciding factor for plant efficiency in wide range of waste water treatment plants. One of the contradictory facts was that higher the COD resulted in lower DO in any water samples. The percentage decrease in COD was 11%, 121%, 400% and 430% in tap water, pond water, domestic waste water and sea water respectively as reported in the figure. Under any testing conditions, the quantity of compounds oxidized biologically is inferior to the quantity of compounds oxidized chemically.

5.2 BIOCHEMICAL OXYGEN DEMAND (BOD):

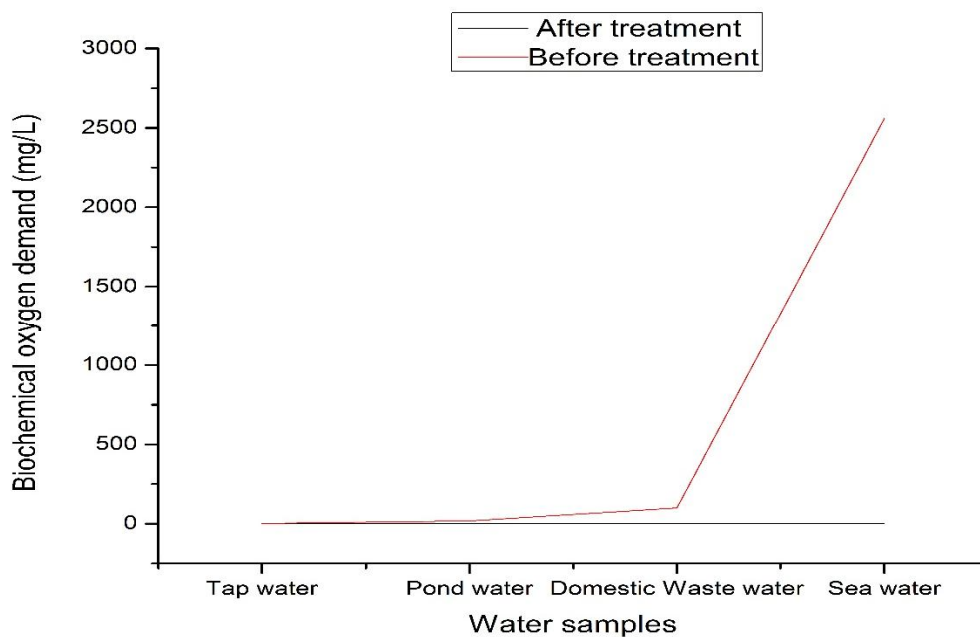


Fig 5.3: Biochemical Oxygen Demand(BOD)

The increase in aerobic microorganisms due to the presence of biological organic pollutants in water require higher amount of oxygen to degrade this pollutant resulted in higher biochemical oxygen demand (BOD) in any tested water samples. The percentage decrease in BOD for tap water, pond water, waste water and sea water was about 3 %, 18 %, 105 % and 2500 % after the formation of NBs in above mentioned samples respectively. The waste water and sea water were found to be with higher BOD due to the existence of organic matters in biological nature.

5.3 DISSOLVED OXYGEN (DO):

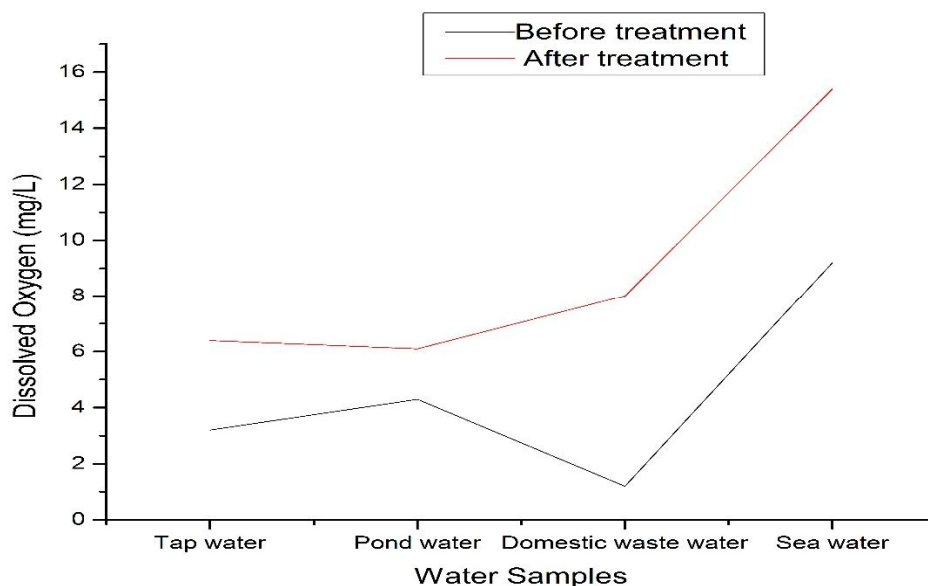


Fig 5.4: Dissolved Oxygen (DO)

From the ambient, the oxygen diffused into the water based on the intensity of heat that exists in tested water samples at controlled thermal environments to ensure the proper degree of saturation of Dissolved oxygen. The dissolved oxygen presence is indirect proportion to the temperature in any liquids due to the activities of inter molecular force. The other contributors for reduced DO level in water are biological oxygen demand, fertilizers and the bacterial growth. The presence of NBs in surface water contributed for the enhancement of biological activity. The minimum DO requirement for living sea fishes is in the order of 5 mg/L. The enrichment of quality of sea water is possible by the generation in NBs in sea water due to the increase in O_2 . The volume fraction of dissolved oxygen (DO) was measured using a high accurate DO meter (0-100 mg/L range). From the figure, it was evident that 50% increase in DO could be achieved in tap water after the generation of free radicals of NBs. In case of stagnant pond water, it was about 66% due to the NBs. In domestic waste water and sea water, this increase in trend was measured to be 300% and 44% respectively. The interesting factor of the experimental results was that stable zeta potential values for the entire DO measured outputs.

5.4 TOTAL SUSPENDED SOLIDS (TSS):

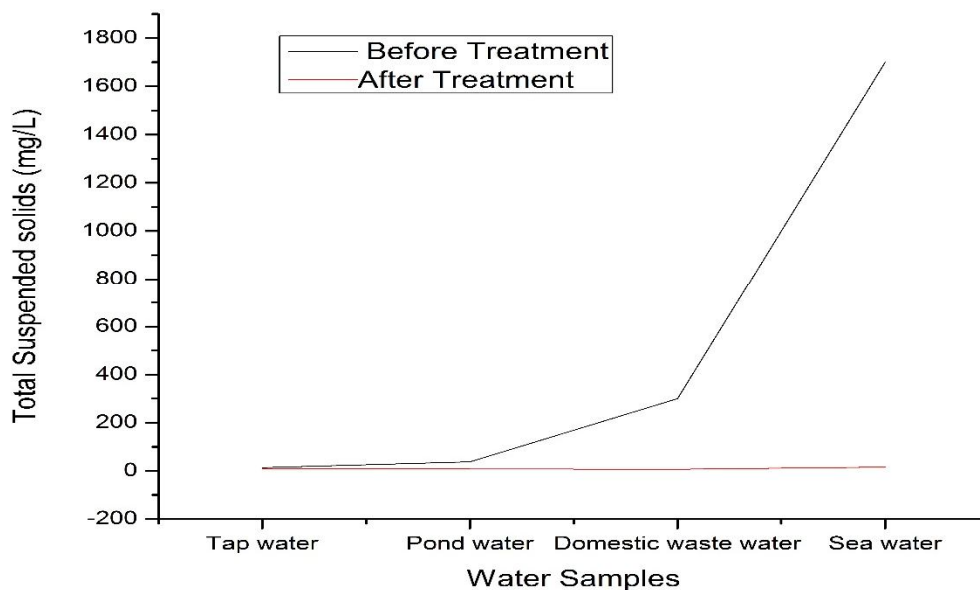


Fig 5.5: Total Suspended Solids (TSS)

The particles (size not less than 2 μm) which were not dissolved in liquid medium due to their weight namely total suspended solids (TSS) attributed for significant research in many fields of science and engineering. Except algae and bacteria, most of the TSS was inorganic in nature. In country like US, it was called as conventional pollutant in water. One of the simplest techniques for the measurement of TSS is filtering through a permeable membrane. The porosity, mesh size and surface roughness of filter are the other contributing factors for proper determination of TSS in any liquid sample. 30.77%, 78.9%, 300% and 1500% reduction in TSS was attained after the generation of NBs in tap water, pond water, domestic waste water and sea water respectively.

5.5 TOTAL DISSOLVED SOLIDS (TDS):

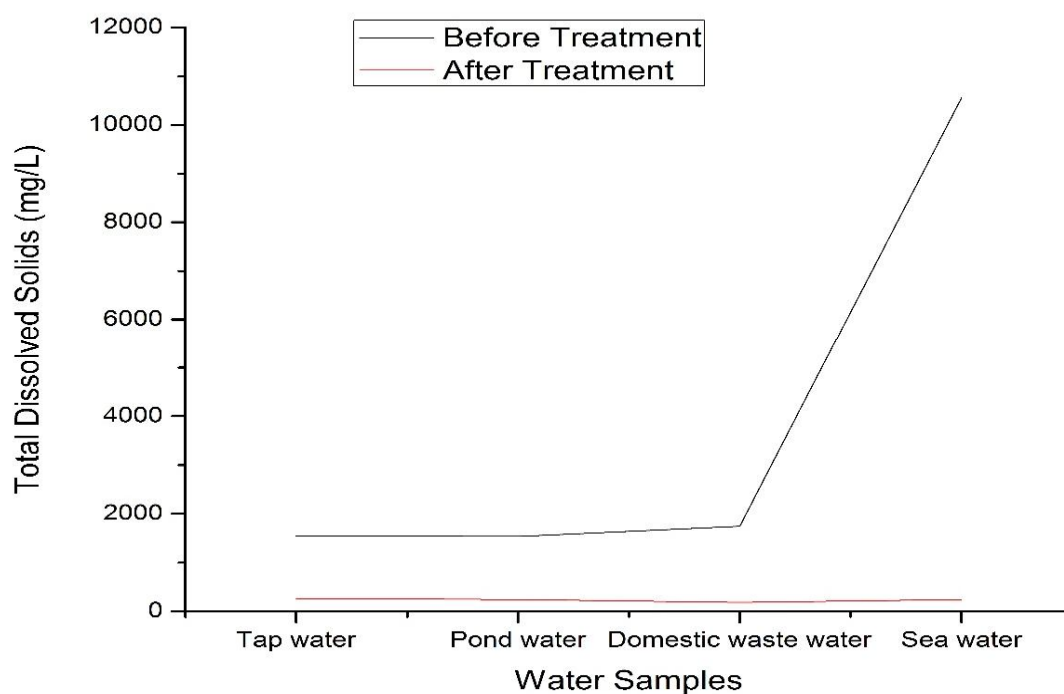


Fig 5.6: Total Dissolved Solids (TDS)

Total dissolved solids (TDS) comprise both the organic and inorganic components present in liquids. The waste water treatment plants major cost incurred in the reduction of TDS due to their varying sizes and behaviors. The 83%, 84.26%, drop in TDS were measured in tap water and pond water respectively before and after treatment with NBs. In domestic waste water and sea water the percentage reduction was measured to be 89.6%, 97.7%. One of the major drawback before treatment was that corrosion increase and decrease in conductivity of the water samples

5.6 TEST SAMPLE:

This result demonstrates the effectiveness of nanobubbles in tap water. Initially, that is before the generation of nanobubbles the BOD, COD, DO, TSS, TDS, nitrate and phosphates contain was more and after the generation of nanobubbles it was observed that the quality of water was improved from bad to good quality

5.6.1 Sample no 1 (Tap water):

Table 5.1: Test report for before and after the presence of nanobubbles in sample no 1 (Tap water)

Sl.No.	Test Parameters	Before (mg/L)	After (mg/L)
1.	Chemical Oxygen Demand (COD)	11	BDL: (4)
2.	Biochemical Oxygen Demand (BOD)	3	BDL: (2)
3.	Dissolved Oxygen (DO)	3.2	6.4
4.	Total Suspended Solids (TSS)	13	9
5.	Total Dissolved Solids	1550	263
6.	Nitrate	25	1.3
7.	Phosphate	4.86	BDL: (0.9)

5.6.2 Sample no 2 (Pond water)

Table 5.2: Test report for before and after the presence of nanobubbles in sample no 2 (Pond water)

Sl.No.	Parameters	Before (mg/L)	After (mg/L)
1.	Chemical Oxygen Demand (COD)	121	BDL: (4)
2.	Biochemical Oxygen Demand (BOD)	18	BDL: (2)
3.	Dissolved Oxygen (DO)	4.2	6.07
4.	Total Suspended Solids (TSS)	38	8
5.	Total Dissolved Solids	1537	242
6.	Nitrate	7	1.4
7.	Phosphate	0.04	BDL: (0.01)

5.6.3 Sample no 3 (Domestic waste water)

Table 5.3: Test report for before and after the presence of nanobubbles in sample no 3 (Domestic waste water)

Sl.No.	Test Parameters	Before (mg/L)	After (mg/L)
1.	Chemical Oxygen Demand (COD)	399	BDL: (4)
2.	Biochemical Oxygen Demand (BOD)	105	BDL: (2)
3.	Dissolved Oxygen (DO)	BDL: (0.2)	7.4
4.	Total Suspended Solids (TSS)	300	BDL: (1)
5.	Total Dissolved Solids	1742	181
6.	Nitrate	4.6	2.2
7.	Phosphate	1.46	BDL: (0.01)

5.6.4 Sample no 4 (Industrial Waste Water)

Table 5.4: Test report for before and after the presence of nanobubbles in sample no 4 (Industrial waste water)

Sl.No.	Test Parameters	Before (mg/L)	After (mg/L)
1.	Chemical Oxygen Demand (COD)	4520	124
2.	Biochemical Oxygen Demand (BOD)	2620	0.17
3	Total Suspended Solids (TSS)	1688	16
4	Total Dissolved Solids (TDS)	10556	242
5	Sulphite	264	BDL: (0.01)
6	Chromium	72.6	BDL: (0.005)
7	Total Suspended Solids (TSS)	12244	258

CHAPTER 6

SUMMARY AND CONCLUSION

The NBs generation with the unique hydrodynamic cavitation technique was adopted in all the water samples such as tap, pond, domestic waste and sea water. It was evident that the dissolved oxygen enrichment was increased to a great extent in all the cases. The TSS and TDS level dropped down to the safe limit. The COD was reduced nearly by 400 % in sea water and least in tap water by 11 % due to the presence of more chemical substances that exist in sea water. The organic pollutants which are biological in nature reduced by 2500 % BOD in sea water with this NBs technique. Without affecting the zeta potential values, the DO % is increased in all four tested water samples. The conventional pollutant called TSS was reduced in the range of 30-300% in as tap, pond, and domestic waste and sea water samples. The corrosion effects were minimized in all the case studies which were validated with the reduction in TDS in the range of 80-100 % after treatment with NBs.

REFERENCES

1. Abdullah F. Alghannam Metabolic limitations of performance and fatigue in football, J.Can. Res Updates 4(2), (2012) 65-73.
2. Andinet Tekile, Ilho Kim, Jai-Yeop Lee Extent and persistence of dissolved oxygen enhancement using nanobubbles Environ. Eng.Res. 2016.
3. AnupGurung, Olli Dahl &KajJansson, The fundamental phenomena of nanobubbles and their behaviour in wastewater treatment technologies, Geosystem Engineering, 19(3), (2016), 1-10.
4. Atia E. Khalifa&Dahiru U. Lawal,Application of response surface and Taguchi optimization techniques to air gap membrane distillation for water desalination—A comparative study, Desalination and Water Treatment, 57:59 (2016) 28513-28530.
5. C.Rameshkumar, S.LakshmiSankar&G.Senthilkumar (2019):Characterisation of seed germination using nanaobubbled water, International Journal of Ambient Energy, DOI: 10.1080/01430750.2019.1672581.
6. C.Rameshkumar,G.Senthilkumar,R.Subalakshmi, RisaGogoi(2019), “Generation and characterization of nanobubbles by ionization method for wastewater treatment” Desalination and Water Treatment, doi:10.5004/dwt.2019.24389 164,98-101.
7. Chang Liu¹², Yuchao Tang¹² Application research of micro and nano bubbles in water pollution control E 3S Web of Conferences,136 ICBTE, 2019.
8. Chih-Wen Yang, Yi-Hsien LuandIng-Shouh Hwang, Imaging surface nanobubbles at graphite–water interfaces with different atomic force microscopy modes, 25(18),(2013).
9. Daniele Vergara, Claudia Bellomo, Xingcai Zhang, Viviana Vergaro, Andrea Tinelli, Vito Lorusso, Ross Rinaldi, Yuri M. Lvov, Stefano Leporatti, Michele MaffiaLapatinib/Paclitaxel polyelectrolyte nanocapsules for overcoming

multidrug resistance in ovarian cancer Nanomedicine: NBM 8 (6), (2012) 891-899

10. G. Senthilkumar, A.M. Rakesh, B.R.S. Aravind Sri Krishna et al., Experimental investigation on the effect of nanobubbled water in evaporative cooling and oxygen enrichment in air cooler, Materials Today: Proceedings, <https://doi.org/10.1016/j.matpr.2020.09.759>
11. G. Senthilkumar, M. Purusothaman, C. Rameshkumar et al., Generation and characterization of nanobubbles for heat transfer applications, Materials Today: Proceedings, <https://doi.org/10.1016/j.matpr.2020.08.373>
12. G. Senthilkumar, S.Lakshmisankar (2018): Bubble dynamic behavior of air water two phase flow mixing in hydraulic structures, International Journal of Ambient Energy, doi:10.1080/01430750.2018.1557549.
13. Gianluca Ferraro, Ananda J. Jadhav and Mostafa Barigou A Henry's law method for generating bulk nanobubbles Nanoscale, Issue 9, 2020.
14. Jifeng Guo, Yingying Li, Dan Hu & Hang Liu, Preparation of transition-metal-doped ZnO nanophotocatalysts and their performance on photocatalytic degradation of antibiotic wastewater, Desalination and Water Treatment, (2014) DOI: 10.1080/19443994.2014.961171
15. Kosuke Ebina, Kenrin Shi, Makoto Hirao, Jun Hashimoto, Yoshitaka Kawato, Shoichi Kaneshiro, Tokimitsu Morimoto¹, Kota Koizumi¹, Hideki Yoshikawa¹ Oxygen and Air Nanobubble Water Solution Promote the Growth of Plants, Fishes, and Mice June 2013 | Volume 8 | Issue 6 Plos One.
16. Mohammad Reza Ghaani, Peter G. Kusalik, Niall J. English Massive generation of metastable bulk nanobubbles in water by external electric fields science advances.vol6, 2020.
17. P. Pattekari, Z. Zheng, X. Zhang T. Levchenko, V. Torchilin, Y. Lvov Top-down and bottom-up approaches in production of aqueous nanocolloids of

- low solubility drug paclitaxel *PhysChemChem Phys.* 13 (19) (2011) 9014-9019
18. Peter Nasr & Hani Sewilam, Investigating fertilizer drawn forward osmosis process for groundwater desalination for irrigation in Egypt, *Desalination and Water Treatment*, 57:56 (2016) 26932-26942, DOI: 10.1080/194439942016.1170639
 19. R. Ahmadi, A. KhodadadiDarban Modeling and Optimization of Nano-bubble Generation Process Using Response Surface Methodology *Int. J. Nanosci. Nanotechnol.*, Vol. 9, No. 3, 2013, pp. 151-162.
 20. S. Gobinath, G. Senthilkumar & Nagappan Beemkumar (2018): Air nanobubble-enhanced combustion study using mustard biodiesel in a common rail direct injection engine, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects* Vol. 41, No. 15, 1809–1816.
 21. S. Mozaffari, P. Tchoukov, J. Atias, J. Czarnecki, N. Nazemifard "Effect of Asphaltene Aggregation on Rheological Properties of Diluted Athabasca Bitumen" *Energy & Fuels*, 29 (9) (2015) 5595–5599.
 22. Saeed Mozaffar, Plamen Tchoukov, Ali Mozaffar, Jesus Atias, Jan Czarnecki, Neda Nazemifar "Capillary driven flow in nanochannels-Application to heavy oil rheology studies" *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 513(5) (2017) 178-187.
 23. Sangbeom Kim¹, Hyounjun Kim², Mooyoung Han³, Tschungil Kim⁴ Generation of sub-micron (nano) bubbles and characterization of their fundamental properties *Environ Eng Res* > Volume 24(3); 2019.
 24. Senthilkumar.G, Rameshkumar C, Nikhil M.N.V.S, Navin Ram Kumar J(2018), "An Investigation of nanobubbles in aqueous solutions for various applications, *Applied Nanoscience* doi:10.1007_s13204-018-0831-8, 8(6), pp.1557-1567.

25. Senthilkumar.G, Rameshkumar C, Nikhil M.N.V.S, Navin Ram Kumar J, "An Investigation of nanobubbles in aqueous solutions for various applications, *Applied Nanoscience*, 8(6) (2018), 1557-1567.
26. Takehiko Sato, Tatsuyuki Nakatani, Takashi Miyahara, Shiroh Ochiai, Masanobu Oizumi, Hidemasa Fujita and Takamichi Miyazaki Study on Formation of Plasma Nanobubbles in Water *Journal of Physics: Conference Series* 656 (2015)
27. Vergaro V, Scarlino F, Bellomo C, Rinaldi R, Vergara D, Maffia M, Baldassarre F, Giannelli G, Zhang X, Lvov YM, Leporatti S, Drug-loaded polyelectrolyte microcapsules for sustained targeting of cancer cells. *Adv Drug Delivery Rev* 63 (9) (2011) 847-864.
28. Yuri M. Lvov, Pravin Pattekari, Xingcai Zhang, Vladimir Torchilin Converting Poorly Soluble Materials into Stable Aqueous Nanocolloids *Langmuir*, 27 (3) (2011) 1212–1217
29. Zhiguo Zheng, Xingcai Zhang, Daniel Carbo, Cheryl Clark, Cherie-Ann Nathan, Yuri Lvov, Sonication-Assisted Synthesis of Polyelectrolyte-Coated Curcumin, Nanoparticles *Langmuir*, 26 (11) (2010) 7679–7681.