

GROUND WATER TREATMENT BY NANOBUBBLE TECHNOLOGY

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in

Mechanical Engineering

by

Ch. TARUN TEJA (38150023)

BASWA JEEVAN KUMAR (38150019)



DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade “A” by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

MARCH- 2022



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www.sathyabama.ac.in

DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIED CERTIFICATE

This is to certify that this Project Report is the bonafied work of **Ch. TARUN TEJA** and **BASWA JEEVAN KUMAR** who carried out the project entitled "**GROUND WATER TREATMENT BY NANOBUBBLE TECHNOLOGY.**" under my supervision from NOV 2021 to MARCH 2022.

**INTERNAL GUIDE
Dr. G. SENTHILKUMAR**

**HEAD OF DEPARTMENT
Dr. G. ARUN KUMAR**

Submitted for Viva voce Examination held on_____.

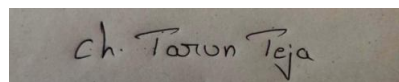
Internal Examiner

External Examiner

DECLARATION

I **Ch. TARUN TEJA** and **BASWA JEEVAN KUMAR** hereby declare that the project report entitled “**GROUND WATER TREATMENT BY NANOBUBBLE TECHNOLOGY**”, done by me under the guidance of **Dr. G. SENTHILKUMAR, M.E., Ph.D.** at **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY, CHENNAI** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.

DATE: 19.4.22

A rectangular box containing a handwritten signature in black ink that reads "Ch. Tarun Teja".A rectangular box containing a handwritten signature in black ink that reads "B. Jeevan".

PLACE: Chennai

SIGNATURE OF CANDIDATES

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to Board of management of **SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my sincere 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 of Mechanical Engineering** for providing me the necessary support and details at the right time during the progressive reviews.

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

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ABSTRACT

The presence of inorganic pollutants, organic pollutants and several insoluble solids made purification of ground water treatment more complicated nowadays. In order to make water sustainable, more effective and less complex solution is required for the treatment of ground water. As decades pass new techniques and new technologies emerge and thereby produced to "Nanotechnology". This project discuss about the treatment of ground water using nanobubble technology. Nanotechnology is the emerging technology in the current generation due to its vast properties. And hence using these nanobubble technologies to improve the drinking water quality. These micro Nanobubbles have the properties like high specific surface areas, excellent gas transfer efficiency and interface potential, as well as the capacity to create free radicals, as well as high stability and extended water residence periods etc,. These NB's are passed into the water by the "Hydrodynamic oxidation method" and their existence is proved by using "Scanning Electron Microscope (SEM)" and "Nano Particle Tracking Analyser (NTA)". And then pH, zeta potential, nanobubble diameter and size are found. The hydrodynamic oxidation is conducted for some time intervals from 5 to 30 minutes and the results are shown. The dissolved oxygen content is brought up to 13.5%, pH is brought down to 6 and the zeta potential is between -5mV to -40mV. After the analysis directed the water is passed for "water quality test" and checked for the "All out Dissolved Solids (TDS)", "Complete Suspended Solids (TSS)", "Broke up Oxygen (DO)", "Biochemical Oxygen Demand (BOD)", "Synthetic Oxygen Demand (COD)", chromium (Cr+3), phosphate (PO_4^{3-}) and sulfide (S^{2-}). And ensured the existence of MNB's in ground water made them pure to some extent and the results are discussed.

KEYWORDS

Dissolved oxygen, Micro-Nanobubbles, Scanning Electron Microscope, Atomic force microscope.

CONTENTS

CHAPTER.NO	TITLE	PAGE.NO
	ABSTRACT	v
	LIST OF ABBREVIATIONS	viii
	LIST OF FIGURES	ix
	LIST OF TABLES	x
1	INTRODCTION	1
	1.1 Basic characteristics' of MNB's	3
	1.2 Methods for characterisation of MNB's	4
	1.2.1 Zeta potential measurement	4
	1.1.2 Size measurement	6
	1.3 Observation from NTA	8
	1.4 Methods for generation of nanobubbles	10
2	LITERATURE SURVEY	13
3	AIM AND SCOPE	17
	3.1 AIM	17
	3.2 SCOPE	17
4	MATERIALS AND METHDOS	18
5	RESULT AND DISCUSSION	22
	5.1 OUTCOME OF RESEARCH	22
	5.2 NEGOTIATION ON RESEARCH DONE	28
	5.3 ANALYSIS	30

5	SUMMARY AND CONCLUSION	32
	6.1 SUMMARY	32
	6.2 CONCLUSION	32
7	REFERENCES	34

LIST OF ABBREVIATIONS:-

MNB's	-	Micro Nano Bubbles
DO	-	Dissolved Oxygen
TDS	-	Total Dissolved Solids
TSS	-	Total Suspended Solids
SEM	-	Scanning Electron Microscope
AFM	-	Atomic Force Microscope
BNB	-	Bulk Nano Bubbles
NTA	-	Nano particle tracking analysis
DLS	-	Dynamic light scattering
BDL	-	Below Deduction Limit

LIST OF FIGURES

FIG	TITLE	PAGE NO
1.1	Behaviour of Macro bubble, micro bubble (MB) and nanobubble (NB).	3
1.2	Defining the zeta potential	4
1.3	SEM image before nanobubble generation	6
1.4	SEM image after nanobubble generation	7
1.5	Bubble number density with the variation of oxidation time	9
4.1	Ground water sample	19
4.2	Equipment for nanobubble generation	21
5.1	Bubble number density with oxidation	23
5.2	Bubble diameter Vs bubble number density at 5 mins	24
5.3	Bubble diameter Vs bubble number density at 10 mins	25
5.4	Bubble diameter Vs bubble number density at 15 mins	26
5.5	Bubble diameter Vs bubble number density at 20 mins	26
5.6	Bubble diameter Vs bubble number density at 25 mins	27
5.7	Bubble diameter Vs bubble number density at 30 mins	28
5.8	Dissolved Oxygen Vs oxidation time	29
5.9	Report	30

LIST OF TABLES

TABLE	TITLE	PAGE.NO
1.1	Stability behaviour of the nanoparticles in the colloidal system	5
4.1	Test results of water sample	20
5.1	Constituents before and generation of nanobubbles	31

CHAPTER - 1

1.INTRODUCTION

One of the most important criteria for ensuring the general population's well-being is the availability of safe drinking water. Water shortage has been listed as the top most worldwide risk in terms of possible effect over the upcoming decade, According to the World Economic Forum in 2015. Water shortage has been listed as the top most worldwide risk in terms of possible effect over the next decade

Nanobubbles are spherical bundles with a diameter of less than 1micrometer that can be found at the solid-liquid interface or scattered in a liquid medium. According to their morphologies and their locations, they can be divided into surface nanobubbles (solid-liquid interface nanobubbles) and bulk nanobubbles. NanoBubbles are gaseous domains with a radius of tens to hundreds of nanometres that are too small to be seen with the naked eye or conventional microscopes. Images taken with an atomic force microscope (AFM) revealed that they form spherical caps, although the exact shape of the NBs is unknown. Nanobubble technology has been used in a variety of industries, including biomedical engineering, agriculture, and a wide range of industrial applications. Due to its small size they can also be used in fewer intrusions surgical procedures. Considering the size of the nanobubbles, the nanobubbles can be categorized into two type's namely micro nanobubbles and macro nanobubbles. The bubbles with diameter less than 1 μm are called as nanobubbles and the bubble diameter between 1 μm to 100 μm is called as micro bubbles and the diameter bigger than 100 μm are called as macro bubbles. These Macro bubbles can easily travel to the top of the liquid surface and burst. Coming to the Micro bubbles, these can easily dissolve in liquids. And then nanobubbles can remain in the liquid for longer duration. There are different applications supported the nano technology within the present world like a) Nano-bubbles also can change the density of water which is used to separate oil from water. b) Nano-bubbles can also purify the surfaces that cannot be scrubbed or surfaces having very small cracks or pores. c) Nano-bubbles can also be used to deliver an greater amount oxygen in liquids. This is extremely beneficial for seed germination as well as in the medical area to assist people who are choking or experiencing breathing difficulties.. The tiny size and stability of nano-bubbles are

reasons for the wide usage of this technology. The increase in the interest on this field of nanobubbles is not only because of its physiochemical properties but also their use in medical industry, ground water treatment, in agricultural purposes, cultivation and propagation of yeast, algae production, froth floatation, ozone generation, surface cleaning techniques, oxygenation of blood, drug delivery, water quality enhancement etc

On discussing about the purification treatment of ground water, air sparging and activated sludge methods are used. The injection of pressured air into polluted ground water causes hydrocarbons to shift state from dissolved to vapour, which is a subsurface contamination treatment strategy. The air is then transferred to vacuum extraction systems, where impurities are removed and pure water is obtained. However this Nanobubble technology made purification much more easier and economic friendly. Recent studies states that NBs can increase the efficiency of mass transfer and produce a higher dissolved oxygen concentrations. Due to its properties, these NB's have a wide range of applications in water treatment, including promoting gas-liquid mass transfer, optimising the usage of oxidising free radicals, and increasing oxidising capacity. And hence this paper discusses about the purification of ground water in the perspective of NB's.

The Hydrodynamic oxidation method has been used for the generation of the nanobubbles in the liquid. The diameter of the bubbles formed by this hydrodynamic oxidation is in the range of 100-200nm. The quantity of bubbles generated are in the order of 10^9 bubbles per ml. Within little span of time the micro bubbles are formed but the time taken for the generation of the nanobubbles is very high. Its due to very small bubble diameter which requires high oxidation time. Although there are lot more techniques for generation of nanobubbles like Hydrodynamic oxidation, Acoustic method, Mechanical Agitation method etc,. The fact we are using this hydrodynamic oxidation technique is that, there is no limitation in the quantity of liquid handled for the generation of the bubbles. The formed macro bubbles and micro bubbles which are generated by hydrodynamic oxidation method rise against gravity due to buoyancy force and burst in gas liquid interface whereas these bulk nanobubbles and surface nanobubbles due to their small size, they rise slowly and live for a longer duration in the liquid.

1.1 BASIC CHARACTERISTICS OF MNB's

MNBs are featured because of their advantage, which incorporate the minuscule size, high unambiguous region, more noteworthy span in water, bigger mass exchange proficiency, high connection point zeta potential, as well as the ability to create hydroxyl extremists. These characters are not quite the same as regular enormous air pockets. As indicated by the idea of lightness, the rising velocity of the air pocket diminishes with the abatement in the size of the air pocket. When contrasted and ordinary air pockets, these MNB's have more modest volume to permit less lightness and more grounded surface which won't permit MNB's to fall in without any problem. As indicated by studies, the developing pace of MNBs more modest than $1\mu\text{m}$ is considerably more slow than Brownian movement. (the irregular movement of particles suspended in a liquid brought about by impacts with the gas or fluid's quick iotas or atoms) thus, MNBs seem to stay stable in water for a drawn out timeframe. MNBs have an essentially higher mass exchange rate on the grounds that, the mass exchange region of the gas-fluid stages decides the mass exchange pace of a gas. MNBs have more prominent connection point zeta potential, which is like colloidal particles, because of the adsorption of particles on the outer layer of air pockets and the development of counter particles on the inside surface. The OH-bunches adsorb at the MNB interface and overwhelm because of the distinction in enthalpy of hydration between OH-particles (-446.8kJ/mol) and H^+ particles (-1104kJ/mol), bringing about a negative charge on the MNB surface. The Zeta possibilities of air, nitrogen, and oxygen MNBs in unadulterated water are -45mV , -37mV , and -40mV , individually. The substance reagent arrangement particles as well as the gas source sway the Zeta capability of MNBs.

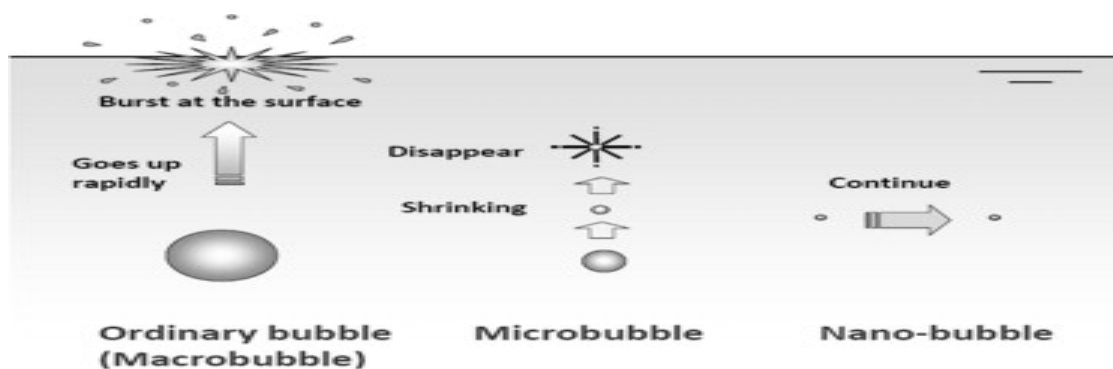


Fig:1.1: Behaviour of Macro bubble, micro bubble (MB) and nanobubble (NB)

1.2 METHODS FOR CHARACTERIZATION OF MNB's

There are two types in characterization of MNB's :

1.2.1. Zeta potential Measurement

1.2.2. Size Measurement

1.2.1 Zeta Potential Measurement

Zeta potential is a physical property which are revealed by particles in water which are suspended and macro molecules etc,. The "zeta potential" is the potential or voltage at the border of the sliding or shear plane in relation to the bulk dispersion medium when ions are no longer in touch with particles in the surface region. If any two adjacent micro bubbles of high zeta magnitude approaches close, they repel each other due to the electrostatic repulsive force(due to same charge on the surface). The other definition as per (Clogston and Patri, 2011; Wei Lu and Ping, 2010) is, "The electric potential in the interfacial twofold layer of a scattered molecule or bead against a point in the ceaseless stage far off from the interfacial is known as zeta potential". The zeta potential is a key bubble surface feature that affects the nanoparticle stability.

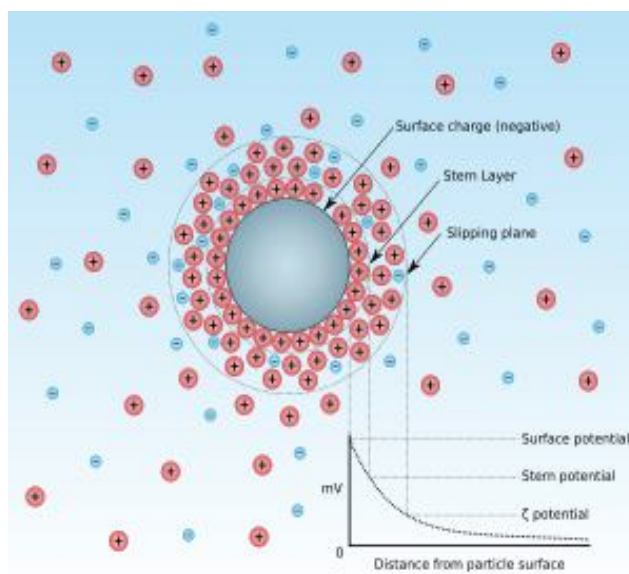


Fig: 1.2: Defining the zeta potential

Zeta potential measurement is a technique for measuring the surface charge of the particles present in the colloidal system. Nanoparticles basically have charge on their

surface which allure the opposite charge to the nanobubble surface called as stern layer. This acts as a double layer for the nanobubble and travels with the nanobubble as it diffuses throughout the solution. In simple terms, The electric potential present at the partition of the double layer is called as Zeta potential. These nanoparticles have zeta potential typically in the range from +100mV to -100mV. The magnitude of the zeta potential determines the stability of the nanobubbles in the solution.

Table 1.1: The behaviour of nanoparticles in terms of stability in the colloidal solution

Zeta potential Value(mV)	Stability behaviour
0 to ± 5 mV	Flocculation or coagulation
± 10 to ± 30 mV	Incipient instability
± 30 to ± 40 mV	Moderate stability
± 40 to ± 60 mV	Good stability
Above ± 60 mV	Excellent stability

There are three methods for deciding the zeta capability of airborne particles: single molecule perception, acoustics, and electrophoretic light dispersing. The cell divider and the base furthest reaches of molecule size cause the electro osmotic rate to be upset while noticing a solitary molecule. Acoustic strategies depend on complex, yet not completely gotten connections among acoustic and electro acoustic properties, molecule size dispersion, charge thickness, and focus. Electrophoretic light dispersing is the most ideal decision as a result of its responsiveness, exactness, and adaptability. Electrophoretic light dispersing gives an outside electric field to the example, and the charged particles in the arrangement moves appropriately. Molecule speed is estimated by the impedance of dispersed light utilizing a laser Doppler velocimeter. Utilizing some reasonable hypothetical model, (for example, the

Henry work), the zeta potential is resolved utilizing the electrophoretic portability. This is determined utilizing the deliberate speed and adequacy of the electric field.

A sample of nanobubble generated water is taken for the measurement of zeta particles. And the value of the zeta potential obtained for us is -5 mV to -40 mV which states that the stability behavior of the water is good from the above table. The reduction in zeta potential is obtained with the increase in the oxidation period of 30min.

1.2.2 Size Measurement

There nanoparticles are also characterized by the size measurement. There are different methods for measuring the size like dynamic light scattering technique, Scanning Electron Microscope(SEM) , Atomic Force Microscope(AFM), acoustic spectroscopy, optical microscopy, image analysis etc., Among all these the instrument we have used for the determination of the size of the nanoparticles is scanning electron microscope. For characterizing the nanoparticles an experimental set up is required. 1ml of sample water before and after nanobubble generation is collected using a syringe and placed on a glass plate. The glass plate was subjected to uniform heating at 100°C and at 1atm pressure. This uniform heating is done because for the evaporation of water vapour to take place. After the evaporation of vapour the plate is placed on the scanning electron microscope to investigate the nature and the size of the nanobubbles. The images of the SEM is shown below.

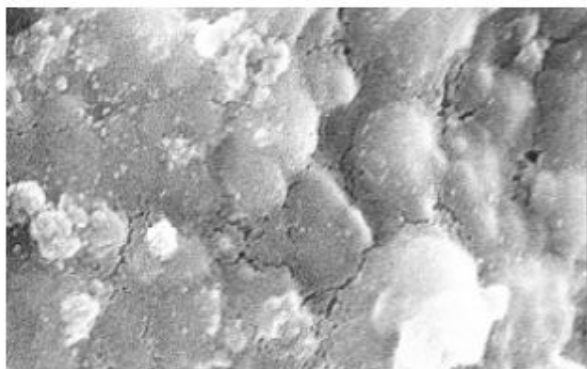


Fig : 1.3: SEM image before nanobubble generation

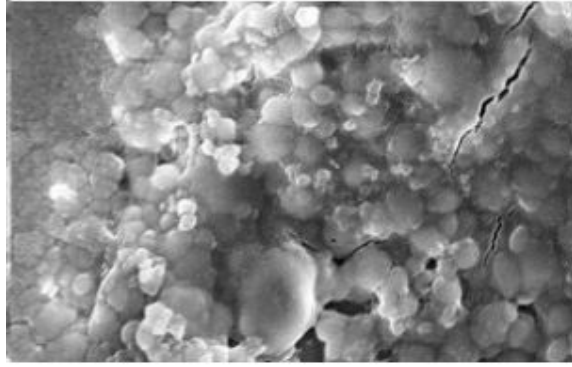


Fig: 1.4: SEM image after nanobubble generation

The average bubble size of the nanoparticle after seeing through scanning electron microscope is 73.56nm and the roughness data of the sample for 2.5 μm ×2.5 μm was found out to be :

Amount of sampling	=	74829
Max	=	169.34 nm
Min	=	0 nm
Peak-to-peak, S_y	=	169.34 nm
Ten point height, S_z	=	80.6382 nm
Average	=	73.5629 nm
Average Roughness, S_a	=	14.05 nm
Root Mean Square, S_q	=	18.92 nm
Second moment	=	2800.12
Surface skewness, S_{sk}	=	0.32481
Coefficient of kurtosis, S_{ka}	=	-0.35002
Entropy (S)	=	8.2381
Redundance	=	-0.31058

The existence of the nanoparticles and their tracking is done by Scanning Electron Microscope and Nano Particle Tracking Analyzers (NTA). This NTA is method for visualizing and analyzing the particles in the liquid. This Nanoparticle tracking analyzer uses both dynamic light dispersing technique furthermore, Brownian movement technique in order to obtain the nanoparticle size variation in the liquid medium. The bubble diameter, bubble density and size distribution are obtained using the Brownian movement. For this a sample of nanobubble generated water is taken at different time intervals. The suspended nanobubbles are subjected to cooling and heating to test the behaviour of the nanobubbles. And the sample is placed in a special chamber inside the NTA which consists of a specially shaped laser beam. In the path of the beam, particles scatter the laser light, which is easily caught by the 20x microscope lens and examined with a digital camera. The camera records a video of the particles moving in Brownian motion. This NTA helps us in determining the size distribution of small particles with diameter of approximately 10-1000nm in liquid medium¹⁴.

1.3 OBSERVATION FROM NTA

This sole purpose of using NTA is to observe the behavior of the nanobubbles. To observe the bubble diameter, bubble size and bubble number density is done using this NTA. The suspended nanobubbles are first subjected to cooling and then subjected to heating for testing the behavior of the nanobubbles. Firstly, a sample of 50ml of nanobubbled water is subjected to cooling up to -15°C for two days in a closed chamber. And after that the sample is heated at a room temperature of 28°C for 5 hours. And then the analysis is done by the Nanoparticle tracking analysis technique. The amount of nanobubbles produced increases with increase in oxidation time. The below shown fig.4.1 is a bar graph representing the bubble number density before freezing and after freezing.

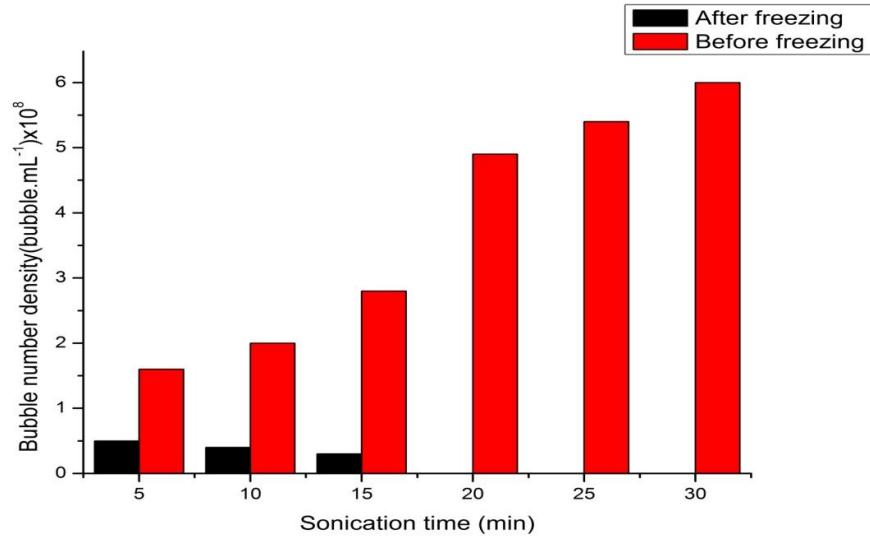


Fig: 1.5: Bubble number density with the variation of oxidation time

The observation found to be surprising. The two bars that are shown in the graph are before freezing and after freezing. The red bar indicates the bubble number density before freezing. The black bar shows the bubble number density after freezing. As seen in the bar graph, the bubble number density is being reduced with the increase in the oxidation time. At higher oxidation time the bubble number density almost reduced to zero after freezing. The bubble number density at oxidation time intervals of 20mins, 25mins, 30mins is almost reduced to zero. This is due to presence of ice molecules. And from the red bars we can conclude that the bubble number density is being increased with power raised to eight. This tells us the presence of the nanobubbles and their bubble number density. At 5 mins of oxidation time interval, the bubble number density before freezing is found to be 1.5×10^8 bubble.mL⁻¹ and the bubble number density after freezing is found to be 0.5×10^8 bubble.mL⁻¹. At 10 mins of oxidation time interval, the bubble number density before freezing is found to be 2×10^8 bubble.mL⁻¹ and the bubble number density after freezing is found to be 0.25×10^8 bubble.mL⁻¹. At 15 mins of oxidation time interval, the bubble number density before freezing is found to be 2.75×10^8 bubble.mL⁻¹ and the bubble number density after freezing is found to be 0.15×10^8 bubble.mL⁻¹. At 20 mins of oxidation time interval, the bubble number density before freezing is found to be 5×10^8 bubble.mL⁻¹ and the bubble number density after freezing is found to be almost null. At 25 mins of oxidation time interval, the bubble number density before freezing is

found to be 5.5×10^8 bubble.mL⁻¹. At 25 mins of oxidation time interval, the bubble number density before freezing is found to be 6×10^8 bubble.mL⁻¹.

1.4 METHODS FOR GENERATION OF NANOBUBBLES

While coming to the discussion of generation of nanobubbles, there are so many techniques in generating them. The different techniques are mentioned below.

- Hydrodynamic oxidation method
- Acoustic method
- Electrochemical method
- Mechanical Agitation method etc.

There are so many other methods are also there for generating the nanobubbles. Lot more reasearch has been done regarding the generation of nanobubbles with minimum power consumption. All these details are discussed clearly in a review published by Parmar and Majumder, 2013. Prior to this, one reasercher named Tsuge, gave a quite explanation on generation of nanobubbles depending on their situation. The different situation are mentioned like,

- When liquid is flowing
- When liquid is not flowing
- When polymers is used
- When low pressure generation techniques is required etc

With regards to the methods of age, cavitation alludes to the creation, development, and breakdown of nanobubbles in arrangement. In light of the kind of age, the cavitation is additionally ordered into four sorts, those are Hydrodynamic, acoustic, optical and molecule cavitation. The cavitaion created by the entry of ultrasonic waves is called as acoustic cavitation. The cavitation delivered by the tension variety in the fluid stream is called as hydrodynamic cavitation.

Hydrodynamic method :

The hydrodynamic strategy chips away at the guideline of cavitation, this causes the development of air pockets. An opening plate or a venturi tube is the generally utilized in the strategy for age. The MB generator of the hole type has an opening in

a water streaming cylinder through which water is compelled to enter the generator. A little distance downstream of the hole, the adjustment of the water speed between the opening and generator outlet causes negative strain. The air is sucked through tempered steel punctured pipe embedded in the running water tube, on the grounds that in order to serious shear power and parts the air into various MB. The venturi type generator mainly consists of three main components, those are, a diverging part, a converging part and a throat. According to J. Haung, simple structure, durability, and more efficiency are the benefits of this generator. Because of its design, the venturi tube has a greater influence on local pressure and cavitation, allowing it to manage bubble size and efficacy..

Acoustic method :

The above discussed hydrodynamic method is mostly used in swirl liquid flow methods and static mixers etc, because these require a continuous flow of circulation to be happen between the generator and the water tank and hence longer time is required to generate the nanobubbles. And mostly these hydrodynamic generators are quite larger due to its complicated components. Keeping all these drawbacks in mind, Acoustic bubble generator came into utilisation for the generation of nanobubbles. These are not complex in design and simple in operation. This Acoustic method uses sound for the generation of the nanobubbles. This sonication gives better performance in surfactant systems, tiny bubble size and larger intrafacial surface area. As per yasudha, the ultrasonic light created NB's as well as diminished the Nb's, in this way arriving at a specific measure of air pocket fixation. Even though, this acoustic approach offers a lot of promise in controlling the bubble size and concentration, these acoustic system is more complex while being compact and automated.

Electrochemical method :

This electrochemical strategy deals with the course of electrolysis. A cathode is plunged in a surfactant arrangement. During the electrolysis cycle, the progression of electricity through the water and the terminals brings about redox response creating hydrogen at anode and oxygen at cathode individually. A few trial results shows that, this age strategy can adjust the air pocket distance across effectively over a wide reach. This experiment is clearly explained by Achaoui. But this generation technique

is not mostly used because of its drawbacks. This generation technique some times causes to explosion which will a major threat to the operator marking the saftey as the main drawback. And moreover, the nanobubbles generated in this generation method is mostly filled with oxygen and hydrogen.

Mechanical agitation method :

This mechanical agitation is purely a manual type method. This method is less complex compared to the other generation techniques, but the bubble size is relatively high and non uniform. While hydrodynamic method is the best for production of large number of bubbles and the acoustic method is best for generating a specific number of bubbles with smaller size. There are no such best to be mentioned for this method. The mechanical agitation usually consists of swirling the liquid, and the amount of bubbles produced is determined by the speed of the mixer or homogenizer. What's more, thus we can reason that because of its bigger size and less centralizations of air pockets, these mechanical tumult generators are less effective. Sir Daryabor expressed that this mechanical disturbance technique plays lost its part as customary strategy for age of air pockets previously. There are lot more emerging techniques coming in the place of generation of bubbles. They have the dominance of simple construction by making them compact, less energy consumption, reducing the cost etc. Such methods include repeated compression of MBs, sonic electrochemical methods.

CHAPTER - 2

LITERATURE SURVEY

- Ariel J. Atkinson, Onur G. Apul, c) Orren Schneider, d) Sergi Garcia-Segura, and e) Paul Westerhoff, "Nanobubble Technologies Supply Chances for Water Treatment Improvement." According to this article, NBs provide chances to improve existing technologies or enable new ones in order to produce fewer by-products and safer water.
- Principles and uses of microbubble and nanobubble water treatment technology. a) Ashutosh Agarwal, b) Wun JernNgYuLiu The science and methods of generating microbubbles (MBs) and nanobubbles (NBs) are discussed, as well as the formation of free radicals from MBs and NBs, with a focus on chemical breakdown, water disinfection, and cleaning of solid materials , including membranes.
- Micro- and nanobubbles' effect and application in water purification Baljinder Singh, Nutan Shukla, Chan-Hyun Cho, Byung Sun Kim, Myoung-Hwan Park, and Kibeom Kim are the members of the team. The present applications of micro- and nanobubbles employing classic and sophisticated methods such as flotation, aeration, and ozonation, which are capable of removing impurities and colour, disinfecting water, and oxidising organic wastes, are discussed in this paper. Bubble technology has emerged as a possible platform for removing harmful chemicals from water utilising these techniques.
- • Water-related application of micro–nanobubble technology. Palwasha Khan, Wenjing Zhu, Feng Huang, Wanlin Gao, and Nasir Abbas Khan are among the candidates. In spite of the prospective role of MNBs in water-connected applications, the current state of research has not yet realised its full potential and strength, according to this study. In particular, a need to improve MNB's use on a larger scale.
- Nanobubble fundamentals and applications Elisavet D. Michailidi, George Bomis, Athanasios Varoutoglou, Eleni K. Efthimiadoua, Evangelos P. Favvasa

- A comparison of mechanical agitation and sonication for the production of microbubbles. Qingyi Xu, Mitsutoshi Nakajima, Sosaku Ichikawa, Nobutaka Nakamura, and Takeo Shiina are the participants. In two surfactant systems, this report compares the production efficiencies of two regularly used methods, mechanical agitation and sonication. In terms of higher gas hold-up, tiny bubble size, and higher interfacial area, the results showed that sonication was highly successful than mechanical agitation in the formation of microbubbles.
- Micro and nanobubble technologies as a new frontier in water treatment. TatekTemesgena, Thi ThuyBui, MooyoungHan, Tschung-ilKim, and HyunjuPark are among the names on the list. This review article integrates research into the fields of microbubbles and nanobubbles, with a focus on water treatment. Based on the explanations of many researchers, the basic definitions of bubbles and its types and their size variations are offered.
- Intensification of microbubble formation and microbubble-assisted transport processes. Rajeev Parmar and Subrata Kumar Majumder are the two candidates. This article intends to present a current state-of-the-art appraisal of the scientific work in microbubble-assisted transport mechanisms that has been done so far. This page discusses the many ways for creating microbubbles as well as the qualities of microbubbles.
- For bioethanol production, a microbubble-free yeast propagation–fermentation process. Vijayendran Raghavendran¹, Joseph P. Webb, Michael L. Cartron, Vicki Springthorpe, Tony R. Larson, and Michael Hines
- <https://nanocomposix.com/pages/zeta-potential-measurements>. The conclusion reached concerns the measurement of the zeta potential and the methods utilised to do so.
- Production and analysis of submicron-sized bubbles. ChendiWu, Kirsten Nasset, Jacob Masliyah, and Zhenghe Xu are the winners. The length of agitation and the temperature had only a little impact on the production of submicron bubbles. Surface features of submicron size bubbles, such as

zeta-potential and its stable nature , were shown to be significantly reliant on the chemistry of the fluids in which the bubbles are formed.

- Properties of micro-nano bubbles and their utilisation in water purification. Mengdi Zhang, Liping Qiu¹, and Guicai Liu are the participants. The usage of MNBs in water oxygenation, pollutant reduction and membrane purifications was explored. These evaluations are meant to enhance theoretical research and practical use of MNBs.
- Groundwater cleanup using micro-nano bubbles. Sabeera Haris, Xiaobin Qiu, Harald Klammler, Mohamed M.A. Mohamed, Xiaobin Qiu, Harald Klammler, Mohamed M.A. Mohamed, Xiaobin Qiu, Xiaobin Qiu, Xiaobin Qiu, Xiaobin Q. This study summarises current findings on the utilisation of MNBs technologies for polluted groundwater remediation. Lastly, the present questions and limitations of MNB's groundwater remediation application are explored.
- A study of nanobubbles in aqueous solutions for a variety of purposes. G. Senthilkumar, C. Rameshkumar, M. N. V. S. Nikhil, and J. Navin Ram Kumar are the members of the team. This document lists the easiest methods for producing nanobubbles in various aqueous solutions, as well as their uses. Chemical oxygen demand, biochemical oxygen demand, total suspended particles, total dissolved solids, dissolved oxygen, nitrate, phosphate, chromium, and sulphide levels were measured in sea water, slurry water, distilled water, and tap water with and without bubbles.
- Microbubble and nanobubble techniques for water purification: principles and applications. YuLiu, Ashutosh Agarwal, ZWun JernNg, Ashutosh Agarwal The physics and methods of producing microbubbles (MBs) and nanobubbles (NBs) are discussed in this paper, as well as the production of free radicals from MBs and NBs, with a focus on toxic compound breakdown, water disinfection, and cleaning/defouling of solid surfaces, including membranes. Because of their propensity to create free radicals, MBs and NBs are believed to have enormous future potential, with much more to be discovered.

- Ionization-based nanobubble generation and characterisation for wastewater treatment. C. Rameshkumar, G. Senthilkumar, R. Subalakshmi, and Risa Gogoid are the candidates.
- Ionization-based nanobubble generation and characterisation for wastewater treatment. C. Rameshkumar, G. Senthilkumar, R. Subalakshmi, and Risa Gogoid are the candidates.
- Nanobubbles Technology for Ethylene Glycol Coolant Oil Heat Transfer Enhancement Case Study A. Sobhanadri, G. Senthilkumar, S. Lakshmi Sankar, M. Purusothaman, C. Rameshkumar Due to its strong anti-freezing properties, the heat transfer potential of Ethylene Glycol (C₂H₆O₂), a coolant for vehicle radiator nanofluids, is examined experimentally in this study. The fluid being tested is a 50:50 mixture containing and ethylene glycol by weight. In the domain of energy conservation, conversion, and recovery, heating systems play a vital role.
- Water and wastewater treatment using ozone micro- and nanobubble technologies. a) Journal of the Korean Society This article provides an overview of the use of micro- and nano bubble ozonation for water and wastewater purification. The disadvantages of previously explored approaches are systematically reviewed, as is the application of hydrodynamic sonication to synthesized aqueous solutions and various industrial effluents.
- The underlying properties of nanobubbles and how they behave in wastewater treatment systems. Anup Gurung, for example. Nanobubbles are generally recognised for their relevance, particularly in terms of their influence in bubble size and stable nature. Nanobubbles are small rounded cap-shaped bubbles with a number of distinct physical and mechanical properties.
- Remediation of groundwater with ozone micro-nano-bubbles. a) ZhiranXia; b) LimingHu. The great efficiency of mass transfer and gas supply in water utilising MNBs is presented in this research. The ozone MNBs approach was used to remediate an organics-contaminated site's ground water in situ.

- Stability of Nanobubbles. a) Jay N. Meegoda, b) Shaini Aluthgun Hewage, and c) Janitha H. Batagoda.

CHAPTER – 3

AIM AND SCOPE

3.1 AIM

The primary aim of this paper is to purify the ground water using nanobubble technology. Besides different techniques that are present in the current world like desalination, distillation etc., purification of groundwater through the nanobubble technology is the new methodology for the purification of ground water. Nanobubble technology is the emerging technology with its wide range of application.

3.2 SCOPE

We humans are contaminating the water for our greediness and uses. The prospective applications of MBs and NBs have gotten a lot of attention in the last few years. Many industries, including the mining industry, medicinal applications, wastewater treatment, surface cleaning, and agriculture, are benefiting from the applications. This nanotechnology is the emerging technology in the current world. So making use of them in the purification of the ground water.

CHAPTER – 4

MATERIALS AND METHODS

The material used in this process is nanobubble generator and collected ground water. Firstly we have collected some ground water, conveniently from our Sathyabama University ground water.

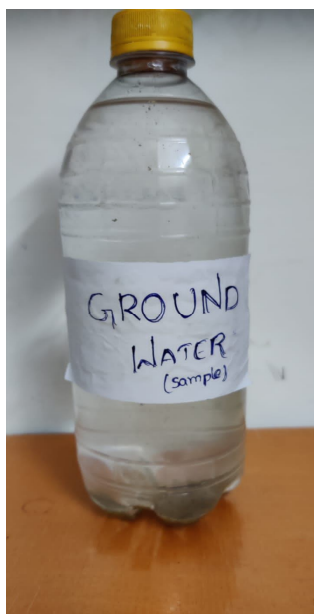


Fig:4.1: Ground water sample

The above is the ground water sample collected. Now the water is sent for the quality test. And asked for some tests in the Chennai Mettlex lab private limited near Guindy, Chennai. The tests that are asked are, pH reading at 25 degrees, dissolved oxygen content (DO), total amount of dissolved solids (TDS), Total suspended solids (TSS), amount of phosphate content, amount of chromium content, amount of sulphides present in the sample, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD). The results are reported as shown in the below table.

TABLE : 4.1: Test result of water sample

Sl.No	Test parameters	Results
1.	pH at 25°C	6.25
2.	Dissolved Oxygen(DO)	5.9 mg/l
3.	Total Dissolved Oxygen (TDS)	1025 mg/l
4.	BOD at 27°C for three days	18 mg/l
5.	COD	93 mg/l
6.	Total Phosphate as P	0.23 mg/l
7.	Total Chromium as Cr	0.201 mg/l
8.	Sulphides as H ₂ S	0.136 mg/l
9.	Total Suspended Solids (TSS)	18 mg/l

From the above test results we can confirm that the ground water is contaminated for some extent. Now the main purpose is to purify this ground water using the nanobubble technology. So, the first and foremost thing to be done is the generation of the nanobubbles. The generation of nanobubbles is done using hydrodynamic oxidation technique. This equipment consists of a motor, inlet valves, outlet valve, a nozzle, oxygen cylinder and a pressure regulator. Amount of air to be sucked is regulated using inlet valve present near the motor to get a controlled flow of air. So that there will be a controlled generation of nanobubbles in the water. The nanobubbles that are generated consists of bulk nanobubbles, micronanobubbles, macronanobubbles. The below figure shows the the equipment used for the generation of the nanobubbles.



Fig : 4.2: Equipment for nanobubble generation

Actually, the generation of nanobubbles is done for different oxidation times like 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, 30 minutes respectively. With the increase in the oxidation times, the bubble number density is also increased. The nanobubbles that are generated collect the impurities from the water. The organic and the inorganic pollutants present in the ground water are being collected from the nanoparticles. The nanobubbles collect the impurities and move to the surface. A membrane or filter is present in the vessel to separate the pure water from the nanobubbles. And after this the water is collected from the outlet valve. Now the water is sent for the purification test in Chennai Mettix lab in Guindy, Chennai. The results are sent within a week.

CHAPTER – 5

RESULT, DISCUSSION AND ANALYSIS

5.1 OUTCOME OF THE PROJECT

The nanobubbles are generated for different oxidation times like 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes and 30 minutes. In each case, it was observed that there is an increase in bubble number density with a difference in the range of 10 power 8 times. So a conclusion is drawn that, the bubble number density is proportional to the oxidation time. That means, if oxidation time increases, the bubble number density also increases.

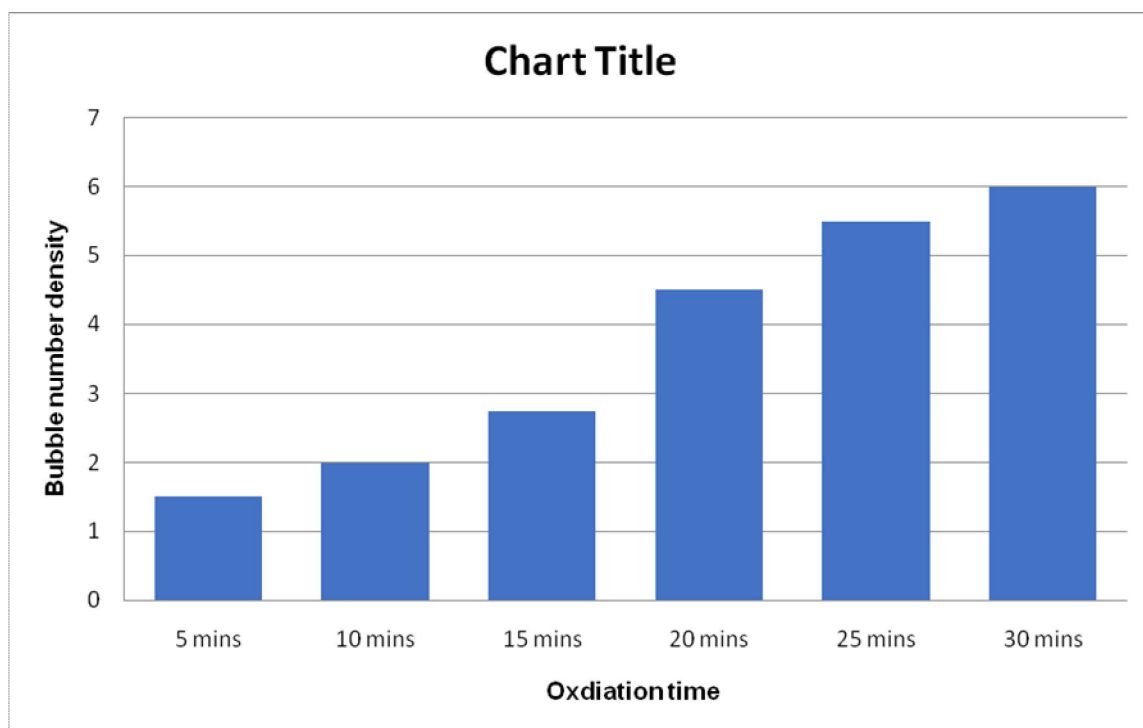


Fig: 5.1: Bubble number density with oxidation time.

The x axis contains the oxidation time and y axis contains the bubble number density0 in the value of 10 raised to power 8.

The bubble characteristics are also studied during this procedure, based on that some conclusions are drawn and that are discussed in the below using graphs. To

understand clearly the procedure is done before freezing and after freezing. The following cases are drawn from that.

Case : 1)

The nanobubble generation is started and the following case is noted at 5 mins of oxidation time. To study the performance of the nanobubbles, the nanobubbled water is made to freeze and then boiled to room temperature. And the graph is taken between the bubble size and the bubble number density at 5 mins of oxidation time.

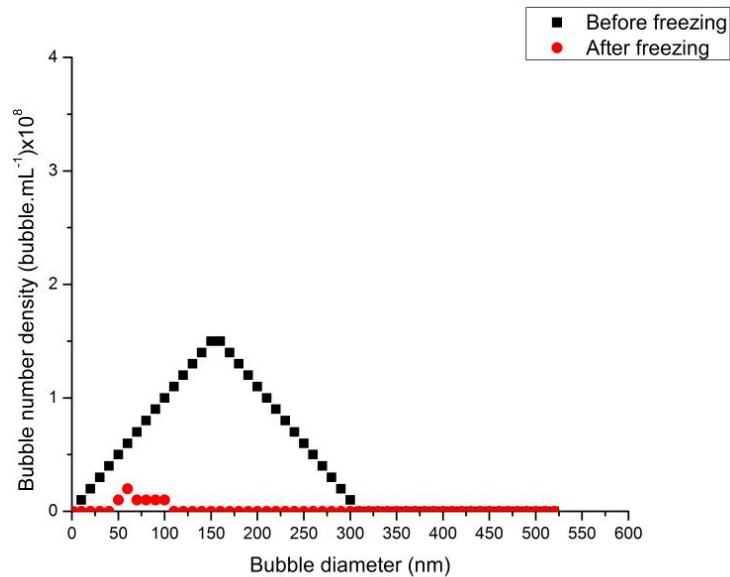


Fig: 5.2: Bubble diameter Vs bubble number density at 5 mins

The above figure portrays the air pocket measurement versus bubble number thickness. The dark spotted lines shows the chart between bubble distance across and bubble number thickness prior to freezing. Though the red spotted lines shows the chart between bubble distance across and bubble number thickness in the wake of freezing. From the red spotted lines we can say that, the air pocket number thickness is decreased because of the presence of ice atoms in the nanobubbled water. Along these lines, the air pockets framed are imploded in the actual water. From the dark spotted it is tracked down that, in case of prior to freezing, the air pocket number thickness is extremely high with the air pocket measurement around 150nm. That suggests that at 5 mins of oxidation there are 1.5×10^8 air pockets/ml

with an air pocket breadth of 150nm.

Case : 2)

Now the oxidation time has increased to 10 mins. The graph between bubble number density and the bubble diameter is as shown below.

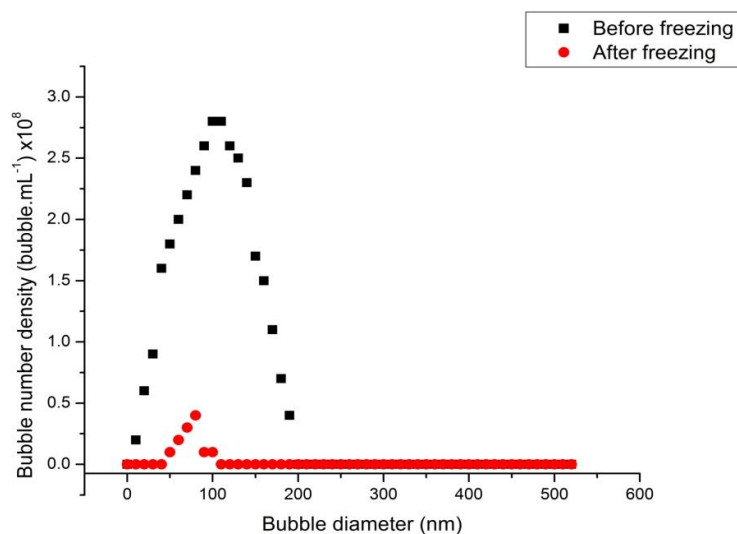


Fig:5.3:Bubble diameter Vs bubble number density at 10 mins

The graph found out to be a logarithmic graph. The black dotted lines indicates the characteristics of nanobubbles before freezing. It is found that the nanobubbles in the case of before freezing are high with the bubble diameter of 100 nm. That implies that at 10 mins of oxidation there are 2.75×10^8 bubbles/ml with a bubble diameter of 100nm. The red dotted lines indicates the the characteristics of nanobubbles after freezing. After freezing, the bubble number density is quite low with a count of 0.5×10^8 bubbles/ml at 100nm bubble diameter.

Case :3)

Now the oxidation has increased to 15 mins. The graph between bubble number density and the bubble diameter is as shown below. It is found that the nanobubbles in the case of before freezing are high with the bubble diameter of 50 nm. That implies that at 15 mins of oxidation there are 4×10^8 bubbles/ml with a bubble diameter of 50nm. The red dotted lines indicates the the characteristics of

nanobubbles after freezing. After freezing, the bubble number density is quite low with a count of 0.5×10^8 bubbles/ml at 50nm bubble diameter.

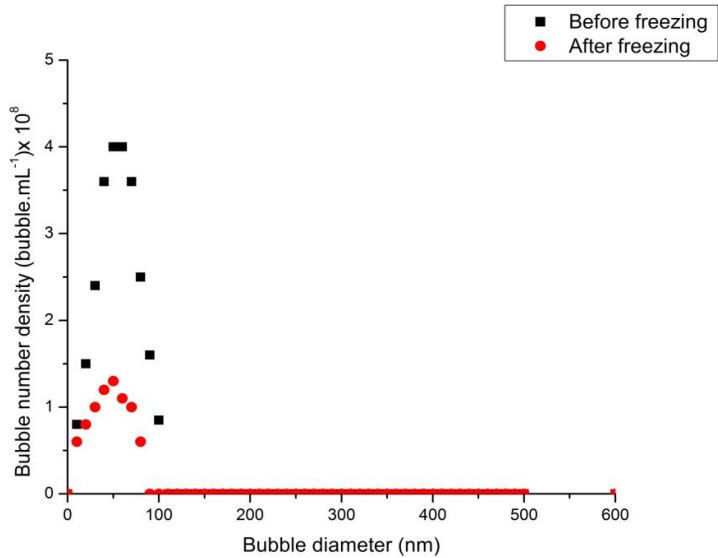


Fig: 5.4: Bubble diameter Vs bubble number density at 15 mins

Case : 4)

The oxidation time is increased to 20 mins and the graph is shown below.

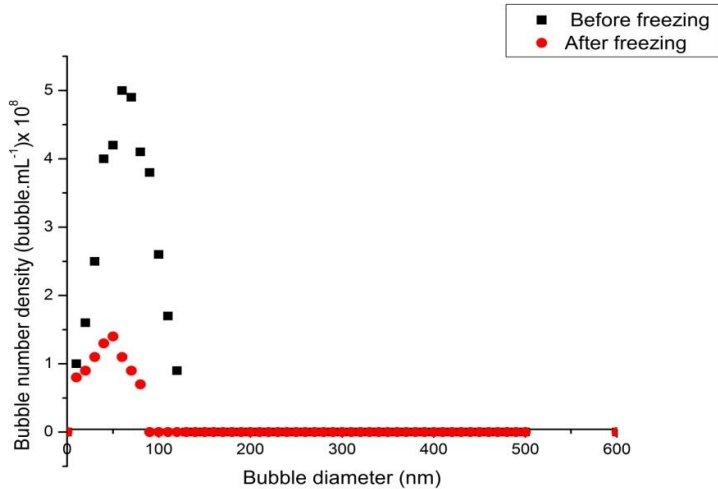


Fig: 5.5: Bubble diameter Vs bubble number density at 20 mins

It is found that the nanobubbles in the case of before freezing are high with the bubble diameter of 50 nm. That implies that at 20 mins of oxidation there are 5 *

10^8 bubbles/ml with a bubble diameter of 50nm. The red dotted lines indicates the the characteristics of nanobubbles after freezing. After freezing, the bubble number density is quite low with a count of 1.5×10^8 bubbles/ml at 50nm bubble diameter.

Case : 5)

The oxidation time is increased to 25 mins and the graph is shown below.

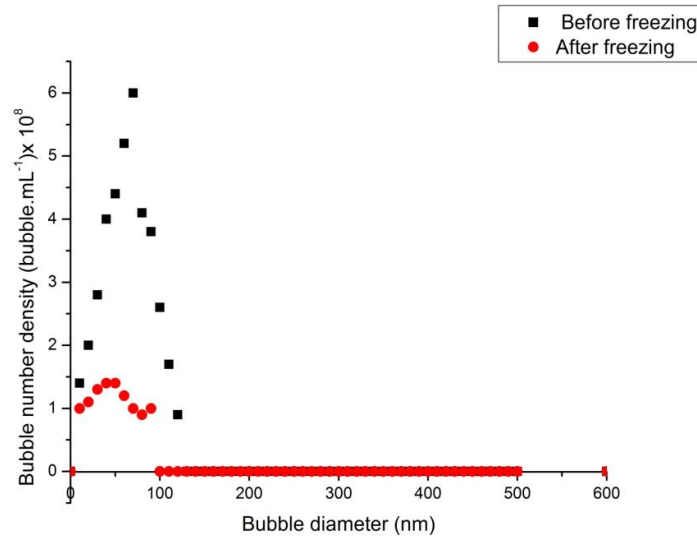


Fig:5.6: Bubble diameter Vs bubble number density at 25 mins

It is found that the nanobubbles in the case of before freezing are high with the bubble diameter of 50 nm. That implies that at 25 mins of oxidation there are 6×10^8 bubbles/ml with a bubble diameter of 50nm. The red dotted lines indicates the the characteristics of nanobubbles after freezing. After freezing, the bubble number density is quite low with a count of 1.5×10^8 bubbles/ml at 50nm bubble diameter.

Case : 6)

The oxidation time is increased to 30 mins and the graph is shown below.

It is found that the nanobubbles in the case of before freezing are high with the bubble diameter of 50 nm. That implies that at 30 mins of oxidation there are 7.5×10^8 bubbles/ml with a bubble diameter of 50nm. The red dotted lines indicates the the characteristics of nanobubbles after freezing. After freezing, the bubble number density is quite low with a count of 1.75×10^8 bubbles/ml at 50nm bubble diameter.

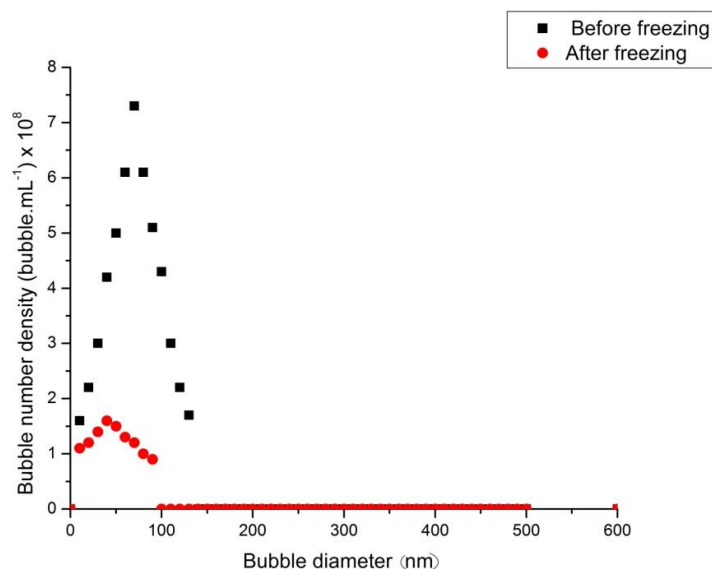


Fig: 5.7: Bubble diameter Vs bubble number density at 30 mins

DISSOLVED OXYGEN :

The amount of oxygen that is present in the water is called as dissolved oxygen. The amount of dissolved oxygen content present in water , tells us a lot about the pure water. Adequate dissolved oxygen amount is good for all water bodies and plants. High amounts of dissolved oxygen can cause issues just as low concentrations can.

After the observation and study on the nanobubbles, we found that, the dissolved oxygen content is increasing with the increase in sonication time i.e., oxidation time. This is because, the nanobubbles are being generated by using air. Air itself contains oxygen content in it. And so thats why, the dissolved oxygen content is drastically increasing with the increase in the oxidation time. The below graph shows the amount of dissolved oxygen content present in different oxidation times.

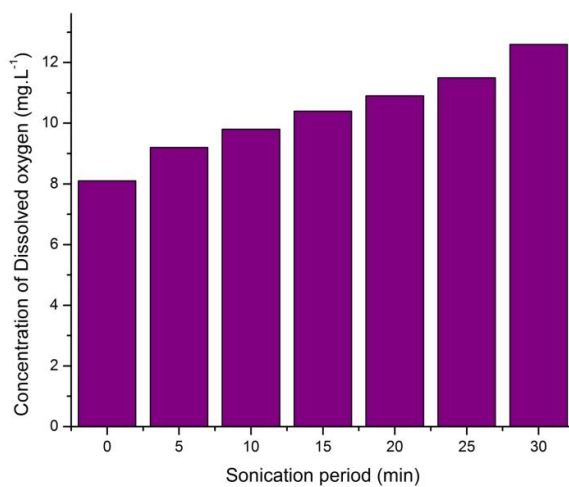


Fig: 5.8: Dissolved oxygen Vs oxidation time.

5.2 NEGOTIATION ON RESEARCH DONE :

After all the results depicted for studying characteristics of the nanobubbles and understanding the bubble number density, bubble diameter and dissolved oxygen content, the next phase is to what extent the water is purified using this nanobubble technology. The water collected after the generation of nanobubbles is sent to laboratory. The tests that are asked in the lab are, pH reading at 25 degrees, dissolved oxygen content (DO), total amount of dissolved solids (TDS), Total suspended solids (TSS), amount of phosphate content, amount of chromium content, amount of sulphides present in the sample, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD). And after a week, the test results are out. And the tests results are shown in the below figure 5.2.1. The below is the report sent from the Chennai Mettex lab private limited.

From the report we can understand that the purification of ground water is done using this nanobubble technology. The pH is brought to the neutral making for the use of drinking water. The amount of Dissolved oxygen content present in the water is 6.4 mg/l. The pure water should contain dissolved oxygen value near to 8.1mg/l. This should be improved.

CHENNAI METTEX LAB PRIVATE LIMITED Jothi Complex, 83, M.K.N. Road, Guindy, Chennai - 600 032.		Phone : 044-22323163, 22311034 42179490, 42179491	 TC - 5589
E-mail : test@mettexlab.com Web : www.mettexlab.com			
TEST REPORT Page No. 1 of 1			
ISSUED TO : Mr. G.Senthil Kumar, B.Jeevan Kumar, P.K.S.Vikranth, T.C Date : 09.02.2022 Sathyabama Institute of Science & Technology, Chennai - 600 119.			
		T.C No : CML/21-22/65107	
		Date Of Receipt : 31.01.2022	
Cust. Ref : SRF Dated : 31.01.2022.		Commenced on : 31.01.2022	
Lab No : 2270413		Completed On : 08.02.2022	
Sample Description : Water - Purified Using Nano Bubble Technology. (as stated by customer)			
S.No	Test Parameters	Test Method	Test Results
Discipline : Chemical		Group : Water	
1	pH at 25°C	IS 3025 Part 11-1983 (Reaff.2017)	7.43
2	Dissolved oxygen	IS 3025 Part 38-1989(Reaff.2014)	6.4 mg/l
3	Total Dissolved Solids	IS 3025 Part 16-1984 (Reaff. 2017)	698 mg/l
4	BOD @ 27°C for 3 days	IS 3025 Part 44-1993 (Reaff.2014)	13 mg/l
5	COD	IS 3025 Part 58-2006(Reaff.2017)	66 mg/l
6	Total Phosphate as P	IS 3025 Part 31-1988 (Reaff.2014)	0.12 mg/l
7	Total Chromium as Cr	IS 3025 Part 2-2004 (Reaff.2014)	0.104 mg/l
8	Sulphide as H ₂ S	IS 3025 Part 29-1986 (Reaff. 2014)	BDL (DL:0.01 mg/l)
9	Total Suspended solids	IS 3025 Part 17-1984 (Reaff.2017)	5 mg/l
Note : BDL - Below Detection Limit, DL - Detection Limit.			
		For Chennai Mettex Lab Private Limited P. KAVITHA Technical Manager	
NOTE: Any unauthorized alteration, forgery or falsification of the content or appearance of this document is unlawful and offenders will be liable for legal action. Unless otherwise stated the submitted results in this test report refer only to the sample(s) tested and such sample(s) are retained for 15 days only from the completion date of testing. Except in case of regulatory samples, which will be retained for a specific period as per statutory requirement; while perishable & environmental testing related remnant samples will be discarded consequent upon completion of testing. Samples are not drawn by us unless otherwise stated. This document cannot be reproduced except in full, without prior written approval of the laboratory. This report is for the exclusive use of Chennai Mettex Lab's customer, and is provided in accordance with			

Fig: 5.9: Report

5.3 ANALYSIS :

Now the analysis is done for the results obtained before and after the experiment conducted. The tabular column for the analysis is shown below.

Table : 5.1: constituents before and generation of nanobubbles

Tests done	Before generation of nanobubbles	After generation of nanobubbles
pH reading at 25°C	6.25	7.43
Dissolved oxygen	5.9 mg/l	6.4 mg/l
Total Dissolved Solids (TDS)	1025 mg/l	698 mg/l
BOD at 27°C for three days	18 mg/l	13 mg/l
COD	93 mg/l	66 mg/l
Total Phosphate as P	0.23 mg/l	0.12 mg/l
Total Chromium as Cr	0.201 mg/l	0.104 mg/l
Sulphides as H ₂ S	0.136 mg/l	BDL
Total Suspended Solids (TSS)	18 mg/l	5 mg/l

The above table depicts the amount of micro constituents that are existing in the water before and after the generation of nanobubbles. Though the tested drinking water possessed lower BOD and COD before treatment it was also evident from the test results that such values were further dropped down to below detection limit and more than 50 % respectively. Every constituent present in the water is reduced more

than its half of its value. The pH is increased from acidic to alkaline i.e., from 6.25 to 7.43. The dissolved oxygen content is also increased from 5.9 mg/l to 6.4 mg/l. This increase in dissolved oxygen content is due to, the procedure used in this project is hydrodynamic oxidation method, which requires air to generate the nanobubbles. And hence the dissolved oxygen is increased. Even though it is increased, the value of the dissolved oxygen obtained is 6.4 mg/l. From the value obtained, the water sample has a good content of dissolved oxygen. The Total dissolved solids is reduced from 1025 mg/l to 698 mg/l. The Biochemical oxygen demand and the chemical oxygen demand also resulted good. The values obtained are 13 mg/l for BOD and 66 mg/l for COD. The amount of sulphide content present in the water after nanobubble generation is reduced to below deduction limit (BDL). The total suspended solids value before the nanobubble generation is 18 mg/l and value after nanobubble generation is 5 mg/l. This shows the affect that is produced by the nanobubbles in the water.

CHAPTER : 6

SUMMARY AND CONCLUSION

6.1 SUMMARY :

Nanotechnology is a term used to represent branches of science and engineering that exploit nanoscale phenomena in the design, characterization, fabrication, and application of materials, structures, devices, and systems. Nanotechnology is becoming a vital technique of water treatment systems. The technique of manipulating atoms on a nanoscale is known as nanotechnology. Nano membranes are used in nanotechnology to soften water while also removing impurities such as physical, biological, and chemical contaminants. The generation of nanobubbles using hydrodynamic oxidation is done. And then using the nanobubbles for the treatment of ground water. And then the water is sent for the testing to test the quality of water. And then some analysis is done using the results obtained.

6.2 CONCLUSION :

- The bubble number density that is formed after the 30 mins of oxidation time is 6×10^8 bubbles/ml using hydrodynamic oxidation technique.
- After the generation of nanobubbles, the water is purified to a greater extent.
- The pH is increased from acidic to alkaline i.e., it is brought from 6.25 to 7.43.
- The size of the bubbles is between 100nm to 200 nm from NTA.
- The stability of the nanobubbles is further increased with high oxidation time.
- The increase in the dissolved oxygen content by 8.14% in the water proved that, this nanobubble technology can be implemented in desalination and other water purification techniques for the improvement of the water quality.
- Because of its particular nature, miniature nano bubbles have been drawing in increasingly more consideration as of late. Up until this point, the instrument of MNB age has been contemplated. The age of air pockets that supplant air, the age of air pockets that structure air, and the age of air pockets by electrolysis. The utilization of MNB generators in mineral lightness, water treatment, transport drag decrease, drug conveyance, and warm stream printing has been ordinarily noticed. However, there are certain areas where MNB application trends appear to be more promising.

- For instance, further developing time and cost productivity because of the low utilization of synthetic compounds, the uses of MNB's have incredible future for ecological supportability regardless to water treatment. Trademark properties, for example, high mass exchange rate, impact effectiveness, less slow rate, changed surface charge and revolutionaries.
- MNB is bound to have a section in future water treatment innovations like sanitization and buoyancy. Such medicines are supposed to bring about additional time cost productivity regarding natural contamination expulsion, buoyancy, air circulation proficiency of organic medicines, and progressed oxidation utilizing OH-particle revolutionaries. The science that produces free extremists has incredible likely while utilizing ozone based MNBs in the oxidation cycle. Besides, MNB's expanded burst energy and air circulation proficiency might assist with lessening film fouling and slop arrangement in layer bioreactors.. Likewise, future exploration on MNB innovation can likewise zero in on streamlining and computerizing MNB generators to tweak the MNB age system in various regions, including enterprises and agribusiness reason. For instance, better computerization in view of savvy innovation control works with the precise use of MNB-based water treatment in agribusiness and can satisfy the developing need for water treatment at different scales. At long last, in spite of the incredible capability of MNB as a brilliant, powerful, and cheap treatment innovation, their applications are as yet restricted to the research facility. Accordingly, future examination and undertakings should be more centered around rural and modern scale advancement and application.

REFERENCES

- 1 A. Chithra, Rajaseetharama Sekar, P. Senthil Kumar, G. Padmalaya. A review on removal strategies of microorganisms from water environment using nanomaterials and their behavioural characteristics. *Chemosphere* **2022**, 295 , 133915. <https://doi.org/10.1016/j.chemosphere.2022.133915>
- 2 Achaoui, Y., Metwally, K., Fouan, D., Hammadi, Z., Morin, R., Debieu, E., Payan, C., Mensah, S., 2017. Tunable microbubble generator using electrolysis and ultrasound. *AIP Advances* 7, 015011. <https://doi.org/10.1063/1.4973720>
- 3 Aghigh, A., Alizadeh,V., Wong,H.Y., Islam Md, S., Amin, N.,Zaman, M., “ Recent advances in utilization of grapheme for filtration and desalination of water : A review. *Desalination*, 365,389-397, 2015.
- 4 Alheshibri M, Qian J, Jehannin M, Craig VSJ (2016) A history of nanobubbles. *Langmuir* 32(43):11086-11100. <https://doi.org/10.1021/acs.langmuir.6b02489>
- 5 Ashutosh Agarwal; Wun Jern Ng; Yu Liu (2011). Principle and applications of microbubble and nanobubble technology for water treatment. , 84(9), 1175–1180. doi:10.1016/j.chemosphere.2011.05.054
- 6 Atchley AA, Prosperetti A (1989) The crevice model of bubble nucleation. *J Acoust Soc Am* 86(3):1065-1084. <https://doi.org/10.1121/1.398098>
- 7 Atkinson AJ, Apul OG, Schneider O, Garcia-Segura S, Westerhoff P (2019) Nanobubble technologies offer opportunities to improve water treatment. *Acc Chem Res* 52(5):1196-1205. <https://doi.org/10.1021/acs.accounts.8b00606>
- 8 Azevedo A, Etchepare R, Calgaroto S, Rubio J (2016) Aqueous dispersions of nanobubbles: generation, properties and features. *Miner Eng* 94:29-37. <https://doi.org/10.1016/j.mineng.2016.05.001>
- 9 Batagoda JH, Hewage SA, Meegoda JN (2019) Nano-ozone bubbles for drinking water treatment. *J Environ Eng Sci* 14(2):57-66. <https://doi.org/10.1680/jenes.18.00015>
- 10 Boshenyatov BV, Kosharidze SI, Levin YK (2019) On the stability of nanobubbles in water. *Russ Phys J* 61(10):1914-1921. [https://doi.org/10.1007/\\$11182-019-01618-x](https://doi.org/10.1007/$11182-019-01618-x)

- 11 C.Rameshkumar, S. LakshmiSankar, G. Senthilkumar, Characterisation of seed germination using nanaobubbled water, *Int. J. Ambient Energy* (2019), <https://doi.org/10.1080/01430750.2019.1672581>.
- 12 Daryabor, M., Ahmadi, A., Zilouei, H., 2017. Solvent extraction of cadmium and zinc from sulphate solutions: Comparison of mechanical agitation and ultrasonic irradiation. *Ultrasonics Sonochemistry* 34, 931–937. <https://doi.org/10.1016/j.ultsonch.2016.07.014>
- 13 Eric C. Ryberg, Johanan Knight, Jae-Hong Kim. Farm-to-Tap Water Treatment: Naturally-Sourced Photosensitizers for Enhanced Solar Disinfection of Drinking Water. *ACS ES&T Engineering* **2021**, 1 (1) , 86-99. <https://doi.org/10.1021/acsestengg.0c00067>
- 14 Fan, M.; Tao, D.; Honaker, R.; Luo, Z. Nanobubble generation and its application in froth flotation (part I): Nanobubble generation and its effects on properties of microbubble and millimeter scale bubble solutions. *Min. Sci. Technol.* 2010, 20, 1–19.
- 15 Fan, W., An, W., Huo, M., Yang, W., Zhu, S., Lin, S., 2020. Solubilization and stabilization for prolonged reactivity of ozone using micro-nano bubbles and ozone-saturated solvent: A promising enhancement for ozonation. *Separation and Purification Technology* 238, 116484. <https://doi.org/10.1016/j.seppur.2019.116484>.
- 16 Frimmel, F.H. and Niessner, R. 2010. Nanoparticles in the water cycle: Properties, analysis and environmental relevance. Springer: USA. 37.
- 17 G Senthilkumar, AM Rakesh, BRS Aravind Sri Krishna, Nivin Joy, S Ganesan, J Hemanandh (2020) Experimental investigation on the effect of nanobubbled water in evaporative cooling and oxygen enrichment in air cooler *Materials Today: Proceedings* doi.org/10.1016/j.matpr.2020.09.759,44(5), pp.3622-3626.
- 18 G. Xie, R. Yang, P. Chen, J. Zhang, X. Tian, S. Wu, J. Zhao, A general route towards defect pore engineering in graphene, *Small* 10 (11) (2014) 2280–2284.
- 19 Geisse, N.A., 2009. AFM and combined optical techniques. *Materials Today*, [https://doi.org/10.1016/S1369-7021\(09\)70201-9](https://doi.org/10.1016/S1369-7021(09)70201-9)

- 20 H. Joost, Weijs and Detlef Lohse, why surface nanobubbles live for hours
Physical review letters, 110(5), (2013) 054501.
- 21 H. Tsuge, Fundamental of microbubbles and nanobubbles, Bulletin of
the Society of Sea Water Science Japan 64 (2010) 4–10
- 22 Hakimeh Hajilou, Solmaz Kazemalilou, Behnam Asgari Lajayer, Ebrahim
Moghiseh, Mehrnaz Hatami. Biogenic nanoparticles and their application for
removal of organic contaminants from water and wastewater. **2022**,, 211-
218. <https://doi.org/10.1016/B978-0-323-91009-5.00010-0>
- 23 Hu, M., Mi, B., “Enabling grapheme oxide nanosheets as water separation
membranes. Environmental Science & Technology, 47(8), 3715-3723.
- 24 Huang, J., Sun, L., Liu, H., Mo, Z., Tang, J., Xie, G., Du, M., 2020. A review
on bubble generation and transportation in Venturi-type bubble generators.
Exp. Comput. Multiph. Flow 2, 123–134. <https://doi.org/10.1007/s42757-019-0049-3>
- 25 I. Ali, New generation adsorbents for water treatment, Chem. Rev. 112 (2012)
5073–5091.
- 26 Jia Xie, Zhipeng Liao, Ming Zhang, Linhan Ni, Junwen Qi, Chaohai Wang,
Xiuyun Sun, Lianjun Wang, Shaobin Wang, Jiansheng Li. Sequential
Ultrafiltration-Catalysis Membrane for Excellent Removal of Multiple Pollutants
in Water. *Environmental Science & Technology* **2021**, 55 (4) , 2652-
2661. <https://doi.org/10.1021/acs.est.0c07418>
- 27 Jin, J., Feng, Z., Yang, F., Gu, N., 2019. Bulk Nanobubbles Fabricated by
Repeated Compression of Microbubbles. Langmuir 35, 4238–4245.
<https://doi.org/10.1021/acs.langmuir.8b04314>
- 28 Jinming Luo, Deyou Yu, Kiril D. Hristovski, Kaixing Fu, Yanwen Shen, Paul
Westerhoff, John C. Crittenden. Critical Review of Advances in Engineering
Nanomaterial Adsorbents for Metal Removal and Recovery from Water:
Mechanism Identification and Engineering Design. *Environmental Science &
Technology* **2021**, 55 (8) , 4287-4304. <https://doi.org/10.1021/acs.est.0c07936>
- 29 Joseph E. Goodwill, Patrick Ray, Destenie Nock, Christopher M.
Miller. Emerging investigator series: moving beyond resilience by considering
antifragility in potable water systems. *Environmental Science: Water*

- 30 Kang, B.-K.; Kim, M.-S.; Park, J.-G. Effect of Dissolved Gases in Water on Acoustic Oxidation and Bubble Growth Rate in 0.83 MHz Megasonic of Interest to Wafer Cleaning. *Ultrason. Sonochem.* 2014, 21, 1496–1503
- 31 Komaba, K., Goto, H., 2019. Micro-Bubble Sonic-Electrochemical Preparation of Polyaniline. *ECS Trans.* 92, 57. <https://doi.org/10.1149/09210.0057ecst>
- 32 M.A. Shannon, P.W. Bohn, M. Elimelech, J.G. Georgiadis, B.J. Marinas, A.M. Mayes, Science and technology for water purification in the coming decades, *Nature* 452 (2008) 301–310.
- 33 Mahmoud, K.A., Mansoor, B., Mansour,a., Khraisheh, M., “ Functional grapheme nanosheets: The next generation membranes for water desalination, *Desalination*,356,208-225,2015.
- 34 Mamadou, S.D. and Savage, N. 2005. Nanoparticles and water quality. *Journal of Nano. Research* 7: 325-330.
- 35 Maoming FAN, Daniel TAO, Rick HONAKER, Zhenfu LUO, Nanobubble generation and its application in froth flotation (part I): nanobubble generation and its effects on properties of microbubble and millimeter scale bubble solutions,*Mining Science and Technology (China)*,Volume 20, Issue 1,2010,Pages 1-19,[https://doi.org/10.1016/S1674-5264\(09\)60154-X](https://doi.org/10.1016/S1674-5264(09)60154-X).
- 36 Minnesota Rural Water Association. 2013. Advancing the science of water: AwwaRF and membrane process. Retrieved from: <http://www.waterrf.org/resources/StateOfTheScienceReports/MembranesResearch.pdf>
- 37 Morito, H., Makuta, T., 2018. Development and Optimization of a Microbubble Generator with a Hollow 1074 Cylindrical Ultrasonic Horn. *Journal of Chemical Engineering of Japan* 51, 175–179.
- 38 P. Pattekari, Z. Zheng, X. Zhan g T. Levchenko, V. Torchilin, Y. Lvov, Top-down and bottom-up approaches in production of aqueous nanocolloids of low solubility drug paclitaxel *Phys Chem Chem Phys.* 13 (19), (2011) 9014-9019

- 39 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 *Phys Chem Chem Phys*. 13 (19), (2011) 9014-9019
- 40 Parmar, Rajeev; Majumder, Subrata Kumar (2013). *Microbubble generation and microbubble-aided transport process intensification—A state-of-the-art report. Chemical Engineering and Processing: Process Intensification*, 64(), 79–97. doi:10.1016/j.cep.2012.12.002
- 41 Pooja Sharma, Kavita Nanda, Mamta Yadav, Ashutosh Shukla, Sudhir Kumar Srivastava, Sunil Kumar, Surendra Pratap Singh. Remediation of noxious wastewater using nanohybrid adsorbent for preventing water pollution. *Chemosphere* **2022**, 292 , 133380. <https://doi.org/10.1016/j.chemosphere.2021.133380>
- 42 Pushpa Kumari Sharma, Rakesh Kumar, Rakesh Kumar Singh, Prabhakar Sharma, Ashok Ghosh. Review on arsenic removal using biochar-based materials. *Groundwater for Sustainable Development* **2022**, 17 , 100740. <https://doi.org/10.1016/j.gsd.2022.100740>
- 43 R. Karthik Raja, Selcuk Hazir, Govindan Balasubramani, G Sivaprakash, Ebenezer Samuel James Obeth, Thulasinathan Boobalan, Arivalagan Pugazhendhi, R Hari Krishna Raj, A Arun. Green nanotechnology for the environment. **2022**,,, 461-478. <https://doi.org/10.1016/B978-0-12-823426-6.00006-1>
- 44 Rajan, C.S. Nanotechnology in groundwater remediation. *International Journal of Environmental Science and Development* 2(3): 1-6. 33.
- 45 S. Yang, J. Li, D. Shao, J. Hu, X. Wang, Adsorption of Ni(II) on oxidized multiwalled carbon nanotubes: Effect of contact time, pH, foreign ions and PAA, *J. Hazard. Matter*. 166 (2009) 109–116
- 46 Sabeera Haris, Xiaobin Qiu, Harald Klammler, Mohamed M.A. Mohamed, DOI: <https://doi.org/10.1016/j.gsd.2020.100463>
- 47 T. Humplik, J. Lee, S.C.O' Hern, B.A. Fellman, M.A. Baig, S.F. Hassan, M.A. Atieh, F. Rahman, T. Laoui, R. Karnik, and E.N. Wang, "Nanostructured materials for water desalination" *nanotechnology*, 22,292001, 2011
- 48 T.A. Kurniawan, M.E.T. Sillanpaa, M. Sillanpaa, Nanoadsorbents for remediation of aquatic environment: local and practical solutions for global

- water pollution problems, *Crit. Rev. Environ. Sci. Technol.* 42 (2012) 1233–1295.
- 49 The use of micro-nano bubbles in groundwater remediation: A comprehensive review
- 50 Tiwari, D.K., Behari, J., Sen, P. 2008. Applications of nanoparticles in wastewater treatment. *World Applied Sciences Journal* 3 (3): 417-433.
- 51 USEPA. 2013. Nanotechnology and Radiation clean up. Retrieved from <http://www.epa.gov/radiation/cleanup/nanotechnology.html>
- 52 Vijayendran Raghavendran, Joseph P. Webb, Michaël L. Cartron, Vicki Springthorpe, Tony R. Larson, Michael Hines, Hamza Mohammed, William B. Zimmerman, Robert K. Poole and Jeffrey Green1 A microbubble-sparged yeast propagation-fermentation process for bioethanol production *Biotechnology for Biofuels* 2020) 13:104 <https://doi.org/10.1186/s13068-020-01745-5>
- 53 Wu, T. Y.; Guo, N.; Teh, C. Y.; Hay, J. X. W. *Theory and Fundamentals of Ultrasound. Advances in Ultrasound Technology for Environmental Remediation*; Springer: Netherlands, Dordrecht, 2013; pp 5–12.
- 54 Xu, Q., Nakajima, M., Ichikawa, S., Nakamura, N., Shiina, T., 2008. A comparative study of microbubble generation by mechanical agitation and sonication. *Innovative Food Science and Emerging Technologies* 9, 489–494. <https://doi.org/10.1016/j.ifset.2008.03.003>
- 55 Y. Manawi, V. Kochkodan, M. Ali Hussein, khaleel, M.A., Khraisheh, M., Hilal, N., “Can carbon-based nanomaterials revolutionize membrane fabrication for water treatment and desalination?”, *Desalination* 391 (2016) 69–88
- 56 Yonghua Liu, Hanqing Chen, Nali Zhu, Jing Zhang, Yufeng Li, Diandou Xu, Yuxi Gao, Jiating Zhao. Detection and remediation of mercury contaminated environment by nanotechnology: Progress and challenges. *Environmental Pollution* **2022**, 293 , 118557. <https://doi.org/10.1016/j.envpol.2021.118557>
- 57 Zhang, K., Dwivedi, V., Chi, C., Wu, J. 2010. Graphene oxide/ferric hydroxide composites for efficient arsenate removal from drinking water. *Journal of Hazardous Materials* 182: 162–168.

58 Zhang, W.X. 2003. Nano-scale iron particles for environmental remediation: an overview. *Journal of Nanoparticle research* 5: 323–332.