

Examining Nanobubbles On Homogenous Surfaces

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

by

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SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

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APRIL - 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the Bonafide work of SHAIK TANVEER MUSHARRAF (Reg.No.39150120), VELAGA BHARGAV DEEPAK (Reg. No.39150130), who have done the Project entitled **"Examining Nanobubbles on Homogenous Surfaces"** Under our supervision from JULY 2022 to APRIL 2023.

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DECLARATION

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DATE: 18.4.2023

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ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to 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 sincere thanks to **Dr. S. Prakash, M.E., Ph.D.**, Dean, School of Mechanical Engineering and **Dr. G. Arun Kumar M.E., Ph.D.**, Head of the Department, Department 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 guide **Dr. G. Senthil Kumar M.E., Ph.D.**, for their valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

I also 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 work.

ABSTRACT

This study aims to investigate the behavior of nanobubbles on hydrophobic and hydrophilic surfaces, specifically on polycarbonate and polyvinyl chloride, respectively. Nanobubbles were generated using the hydrodynamic cavitation method, and their existence was confirmed using dynamic light scattering. The hydrophobic and hydrophilic surfaces were immersed in the nanobubbled water for 10 minutes and then exposed to sunlight until the water evaporated. High-resolution photography was used to capture images of the surfaces. Additionally, a strip of glass was injected with the nanobubbled water and analyzed using atomic force microscopy to determine particle size and distribution. The results indicate that nanobubbles exhibit differing behavior on hydrophobic and hydrophilic surfaces, with significant differences observed in terms of size and distribution. The potential applications of this research include the development of novel anti-fogging and anti-dust coatings for a variety of industrial and consumer products. Further research is necessary to investigate the long-term stability of the nanobubbles under various environmental conditions. These findings contribute to the growing body of knowledge on nanobubbles and their potential applications in surface engineering.

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CHAPTER 1

INTRODUCTION

Nanobubbles are sub-micron sized gas bubbles that can exist in water for extended periods of time due to their high internal pressure. They have unique properties that make them useful in various applications such as medicine, wastewater treatment, and surface engineering.

Importance of nanobubbles in surface engineering Nanobubbles have been shown to be effective in surface cleaning, anti-fouling, and anti-corrosion applications. They can modify surface properties such as wettability, roughness, and adhesion, which can be beneficial in a variety of industrial and environmental settings.

Brief history of research on nanobubbles Research on nanobubbles dates back to the 19th century, but it was not until the 21st century that significant progress was made in understanding their properties and applications. Recent advances in nanotechnology and materials science have enabled better manipulation and control of nanobubbles, leading to the exploration of their potential in various fields.

The behavior of nanobubbles on hydrophobic and hydrophilic surfaces can influence their potential applications in surface engineering. Understanding how they interact with different surface types can inform the design of surface modification strategies and lead to the development of novel materials.

Nanobubbles have shown promise in various surface engineering applications such as cleaning, anti-fouling, and anti-corrosion. Exploring their potential in these areas can provide valuable insights into their use in different industrial and environmental settings.

Overview of experimental methods used to generate and analyze nanobubbles In this study, nanobubbles were generated using hydrodynamic cavitation method, and their existence was confirmed using

Dynamic Light Scattering (DLS). Atomic Force Microscopy (AFM) was used to examine the size and distribution of nanobubbles on a glass surface. The behavior of nanobubbles on hydrophobic (polycarbonate) and hydrophilic (polyvinyl chloride) surfaces was examined by immersing them in nanobubbled water and exposing them to sunlight.

Description of materials and equipment used in the study The materials used in this study include polycarbonate and polyvinyl chloride surfaces, glass slides, and deionized water. The equipment used includes a hydrodynamic cavitation system, a DLS instrument, an AFM system, and a high-resolution camera

CHAPTER 2

LITERATURE SURVEY

Agarwal A, Ng WJ, Liu Y (2011a) Principle and applications of microbubble and nanobubble technology for water treatment. Nanobubbles (NBs) are very tiny bubbles with an approximate diameter of 10–50 μm and <200nm.

Wu C, Nasset K, Masliyah J, Xu Z (2012) Generation and characterization of submicron size bubbles. *Adv Colloid Interface Sci* 179:123–132 Nano-bubbles are formed when a homogeneous liquid phase undergoes a phase change due to a sudden pressure drop below a critical value known as cavitation. This cavitation is formed by ultrasonic waves in passage or changes in high pressure in running fluid.

C.H. Li, G.P. Peterson (2007) - Al_2O_3 and distilled water nanofluids' effective thermal conductivity was assessed using the steady-state approach. Tests were performed for volume fractions ranging from 0.5% to 6.0% at temperatures between 27 and 37 $^{\circ}\text{C}$. The impact of particle size variations on the Al_2O_3 –distilled water nanofluids' effective thermal conductivity was the most important discovery. At a temperature of about 32 $^{\circ}\text{C}$ and a volume percentage of between 2% and 4%, the highest enhancement difference was seen. The enhancement factor for this range of volume fractions for the evaluated temperature range peaked in the experimental data, suggesting that there is an ideal size for various nanoparticle and base fluid combinations.

Fedele, L., Colla, L., & Bobbo, S. (2012) - Water-based nanofluids include titanium oxide (TiO_2) at mass concentrations ranging from 1 to 35%. Their characterization is discussed. First, the stability of the nanofluid is evaluated using measurements of the zeta potential, and the mean nanoparticle sizes are investigated using the dynamic light scattering (DLS) method. The behaviour of viscosity as a function of composition and temperature is then evaluated using a rheometer in the 283 K to 343 K temperature range. In order to understand how temperature and

nanoparticle concentration may effect its potential improvement, the thermal conductivity of these nanofluids is also investigated.

Kaufui VW, Omar DL (2010) - This study focuses on showing the wide range of current and future applications using nanofluids, highlighting their enhanced controlled heat transfer properties and the distinct properties that these nanofluids possess that make them suited for such applications. Nanofluids are fluid suspensions of nanoparticles that exhibit notable property enhancements even at low nanoparticle concentrations. It has also been stated that nanofluid acts as a smart fluid with variable heat transmission.

M. Chandrasekar, S. Suresh, A. Chandra Bose(2010) - An $\text{Al}_2\text{O}_3/\text{H}_2\text{O}$ nanofluid's thermal conductivity and viscosity are investigated in this study. The distilled water was used to make the nanofluid, and the Al_2O_3 nanoparticles were produced using the microwave-aided chemical precipitation procedure. Al_2O_3 /water nanofluids with varying volume contents (0.3–5%) and nominal diameters of 43 nm were used for the study. Testing of nanofluids' viscosity and thermal conductivity reveals that the viscosity increase is noticeably greater than the thermal conductivity increase. Nanofluids become more viscous and thermally conductive as the volume concentration of nanoparticles rises.

Mutuku, W.N. (2016) - This study looks into the cooling properties of a nanofluid made of ethylene glycol (EG) and three different kinds of nanoparticles: copper oxide (CuO), aluminium oxide (Al_2O_3), and titanium dioxide (TiO_2). Due to their improved thermophysical characteristics, nanofluids can be employed in a wide range of mechanical and engineering applications, such as cooling electronics, vehicles, transformers, computers, and electrical equipment. To demonstrate the impacts of the relevant factors on the velocity, temperature, skin friction coefficient, and local Nusselt number, a parametric investigation of the complete flow regime is conducted.

S.K. Das, N. Putra, P. Thiesen, W. RoetzelS.K. Das, N. Putra, P. Thiesen, W. Roetzel (2003) - Nanofluids are regular heat transfer fluids with suspended incredibly small particles of nanoscale size, representing a new level in heat transfer processes. Nanofluids can enhance heat transmission, which is vital for contemporary technology, according to recent studies. The current investigation looks closely at the thermal conductivity of nanofluids made of water as the base fluid and Al_2O_3 or CuO particles as the suspension component. Thermal

conductivity is calculated from thermal diffusivity using a temperature oscillation technique. The results demonstrate that enhancing properties increase with temperature, which greatly increases the attraction of nanofluids for high energy density applications compared to previously published normal room temperature data.

Pourfarhang, S, ZeinaliHeris, S, Shokrgozar, M, Kahani, M.," (2015) - We looked at the function of nanofluid in a specific car radiator and how varied volume concentrations affected pressure drop and fluid flow friction. CuO nanoparticles were evenly disseminated to create stable nanofluids using ethylene glycol (EG) and distilled water in a 60/40 ratio as the host fluid. At three distinct inlet fluid temperatures (35, 44, and 54 °C), the radiator's effect of nanofluid concentrations on pressure drop was assessed. The findings showed that the presence of nanoparticles increased the pressure drop in nanofluid, which was exacerbated by increasing nanoparticle concentration as well as lowering fluid inlet temperature.

S.K. Das, N. Putra, P. Thiesen, W. RoetzelS.K. Das, N. Putra, P. Thiesen, W. Roetzel (2003) - Nanofluids are regular heat transfer fluids with suspended incredibly small particles of nanoscale size, representing a new level in heat transfer processes. Nanofluids can enhance heat transmission, which is vital for contemporary technology, according to recent studies. The current investigation looks closely at the thermal conductivity of nanofluids made of water as the base fluid and Al₂O₃ or CuO particles as the suspension component. Thermal conductivity is calculated from thermal diffusivity using a temperature oscillation technique. The results demonstrate that enhancing properties increase with temperature, which greatly increases the attraction of nanofluids for high energy density applications compared to previously published normal room temperature data.

S.U.S. Choi (1995) -They contend that a whole new class of heat transfer fluids might be produced by floating metallic nanoparticles in conventional heat transfer fluids. Since they are anticipated to have higher thermal conductivities than the heat transfer fluids now in use, the resulting nanofluids offer the greatest potential to enhance heat transmission. The results of a theoretical study on copper nanophase materials' thermal conductivity in nanofluids are provided, along with an assessment of the fluids' potential benefits. One of these benefits—which has been demonstrated—will be a considerable reduction in the power required to

pump heat exchangers.

Timofeeva, E.V., Yu, W., France, D.M., Singh, D., Routbort, J.L. (2011) - It is explained how the viscosity, thermal conductivity, and cooling efficiency of nanofluids are affected at the nanoscale. Because of the extraordinarily high surface-to-volume ratio in nanofluids, a nanoparticle suspension is thought of as a three-phase system consisting of the solid phase (nanoparticles), the liquid phase (fluid medium), and the interfacial phase. A thorough analysis of numerous parameters in the multivariable nanofluid systems was produced because of using the systems engineering method to nanofluid design. Engineering nanofluids with the appropriate set of attributes is made possible by the relative significance of nanofluid parameters for heat transfer examined in this article.

Zhu, D., Li, X., Wang, N., Wang, X., Gao, J., Li, H., (2009) - In this study, Al_2O_3 - H_2O nanofluids were synthesized, and their dispersion behaviours and thermal conductivity in water were investigated under different pH values and different (SDBS) concentrations. The zeta potential and particle size of the particles were measured and the (DLVO) theory was used to calculate attractive and repulsive potentials. The thermal conductivity was measured by a hot disk thermal constants analyser. The results showed that the stability and thermal conductivity enhancements of Al_2O_3 - H_2O nanofluids are highly dependent on pH values and different SDBS dispersant concentrations of nano-suspensions. The Al_2O_3 - H_2O nanofluids with an ounce of Al_2O_3 have noticeably higher thermal conductivity than the base fluid without nanoparticles, for Al_2O_3 nanoparticles at a weight fraction of (0.15wt%), thermal conductivity was enhanced by up to 10.1

Kaufui VW, Omar DL (2010) - This study focuses on showing the wide range of current and future applications using nanofluids, highlighting their enhanced controlled heat transfer properties and the distinct properties that these nanofluids possess that make them suited for such applications. Nanofluids are fluid suspensions of nanoparticles that exhibit notable property enhancements even at low nanoparticle concentrations. It has also been stated that nanofluid acts as a smart fluid with variable heat transmission.

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S.K. Das, N. Putra, P. Thiesen, W. Roetzel S.K. Das, N. Putra, P. Thiesen, W. Roetzel (2003) - Nanofluids are regular heat transfer fluids with suspended incredibly small particles of nanoscale size, representing a new level in heat transfer processes. Nanofluids can enhance heat transmission, which is vital for contemporary technology, according to recent studies. The current investigation looks closely at the thermal conductivity of nanofluids made of water as the base fluid and Al_2O_3 or CuO particles as the suspension component. Thermal conductivity is calculated from thermal diffusivity using a temperature oscillation technique. The results demonstrate that enhancing properties increase with temperature, which greatly increases the attraction of nanofluids for high energy density applications compared to previously published normal room temperature data.

Adleman JR, Boyd DA, Goodwin DG, Psaltis D (2009) - Plasmon heating is used to mediate heterogeneous catalysis. The method makes use of the plasmon resonance to provide the necessary heat of the reaction when a low-power laser is used to illuminate tiny metal catalysts. We demonstrate the efficiency of our approach by reforming a flowing, liquid mixture of ethanol and water over gold nanoparticle catalysts in a microfluidic channel. The CO_2 , CO , and H_2 byproducts of the reaction are consistent with the catalytic steam reforming of ethanol. The technique, which we refer to as plasmon-assisted catalysis, is all-inclusive and may be used to a variety of endothermic catalytic processes involving nanoparticles.

Bickford L., Chang J., Fu K., Sun J., Hu Y., Gobin A., Yu T.K., Drezek

R. Nanobiotechnology (2008) - This article gives a broad review of the most recent developments and ongoing difficulties in the biomedical use of gold nanoparticles of different sizes, shapes, and architectures. The use of gold nanoparticle conjugates in biomedical diagnostics and analytics, photothermal and photodynamic therapies, as a vehicle for delivering target molecules, as well as their immunological and toxicological properties, are the main topics of this review.

Boyd DA, Greengard L, Brongersma L, El-Naggar MY, Goodwin DG (2006) - By patterning the spatial deposition of PbO and TiO₂ on glass substrates coated with a dispersion of 23 nm gold particles, the technique known as plasmon-assisted CVD (PACVD) is demonstrated here. The gold particles were locally heated by a laser by more than 150 degrees C based on the morphology of both oxide deposits. We demonstrate that these sizeable temperature changes are in line with our analysis of the mechanisms causing heat loss. Since virtually every material for which a CVD process is available can be spatially controlled, the technique is universal and can be applied to this.

Cai W, White JS, Brongersma ML (2009) - Electrooptic plasmonic modulators that are small, quick, and power-efficient, specific design and optimisation methods for electrooptic plasmonic modulators that are suited for on-chip integration and free-space coupling are examined. The suggested gadgets' metallic constructions perform simultaneous electrical and optical tasks. These devices can operate at high speeds because of their resonance-enhanced nonlinear interaction and submicrometer footprint, which satisfy the strict specifications for upcoming CMOS modulators.

Cao L, Barsic DN, Guichard AR, Brongersma ML (2007) – Using a concentrated laser beam, scientists have shown in this work a novel, adaptable method for quickly heating and cooling subdiffraction-limited amounts of material. Using metallic nanostructures' distinctive optical capabilities, which efficiently convert light into heat by activating surface plasmons, results in the local temperature increase (collective electron oscillations). This technique opens up new avenues for controlling a variety of significant thermally stimulated processes and the creation of novel photothermal devices by selectively heating nanoscale metallic catalysts. By doing so, growth of semiconductor nanowires and carbon nanotubes can be initiated and controlled at arbitrary prespecified locations and down to the single nanostructure level in a room-temperature chamber.

Chen S, Pei R, Zhao T, and Dyer D.J. (2002) - The complexation interaction between pyridine moieties and divalent metal ions was used in this study to create gold nanoparticles. In relation to their hydrophobicity and interactions with surface-bound particle molecules, the influence of the electrolyte ions' nature was examined. The solution composition was discovered to affect the nanoparticles' onset volumetric potential and effective molecular capacitance.

C.H. Li, G.P. Peterson (2007) - Al₂O₃ and distilled water nanofluids' effective thermal conductivity was assessed using the steady-state approach. Experiments were performed for volume fractions ranging from 0.5% to 6.0% at temperatures between 27 and 37 °C. The impact of particle size variations on the Al₂O₃–distilled water nanofluids' effective thermal conductivity was the most important discovery. At a temperature of about 32 °C and a volume percentage of between 2% and 4%, the highest enhancement difference was seen. The enhancement factor for this range of volume fractions for the evaluated temperature range peaked in the experimental data, suggesting that there is an ideal size for various nanoparticle and base fluid combinations.

Choudhuri B, Mondal A, Dhar JC, Singh NK, Goswami T, Chattopadhyay KK (2013)

- They looked at the glancing angle deposition method used to create arrays of indium (In) nanoparticles on TiO₂ thin films (TF). The size range of the deposited In NPs is between 4 and 10 nm. Optical absorption tests show that In-NPs/TiO₂-TF exhibits 2.5 times more absorption than TiO₂ TF. With continuous light exposures of 1–30 minutes, the device current increases from 1.6 to 6.5 mA/cm² (+5 V) with improved temperature. Comparing the plasmonic device to the TiO₂ TF-based device, the photoresponsivity of the plasmonic device is eight times more (+2.3 V).

Christopher P, Xin HL, Linic S (2011) - They have demonstrated that silver plasmonic nanostructures can drive catalytic oxidation reactions like ethylene epoxidation, CO oxidation, and NH₃ oxidation at lower temperatures than their conventional counterparts that use only thermal stimulus. The visible light used is of a low intensity (on the order of solar intensity). We hypothesise that excited plasmons on the silver surface act to populate O₂ antibonding orbitals and subsequently form a transient negative-ion state, which thereby facilitates the rate-limiting O₂- dissociation reaction. Our hypothesis is based on kinetic isotope experiments and density functional calculations.

C.-Y. Wen, M. Tang, J. Hu, L.-L. Wu, D.-W. Pang, J.-B. Zeng, and X.-Y. Li,

Anal (2016) - A new lateral flow test was developed to detect protein biomarkers using fluorescent nanospheres (FNs) as reporters. Each FN contains 332 quantum dots, making it 380 times brighter than a single quantum dot. By using an immunofluorescent nanosphere (IFN)-based lateral flow test strip, the test was

able to detect C-reaction protein (CRP) at a concentration as low as 27.8 pM, which is 257 times more sensitive than a typical Au-based lateral flow test strip. The test remained stable after six months of storage, maintaining both the bioactivity of IFNs and the fluorescence intensity of FNs.

CHAPTER 3

AIM AND SCOPE

The aim of this study is to investigate the behavior of nanobubbles on hydrophobic and hydrophilic surfaces, as well as explore the potential applications of nanobubbles in surface engineering.

Nanobubbles, as previously defined, are tiny bubbles with a diameter of less than 100 nanometers. Despite their small size, nanobubbles have been found to exhibit unique properties such as long lifetimes, high stability, and strong adsorption to surfaces. These properties make nanobubbles promising candidates for a variety of applications in surface engineering, including surface cleaning, anti-fogging, and anti-dust.

The behavior of nanobubbles on hydrophobic and hydrophilic surfaces is of particular interest in this study, as different surface properties can affect the interaction between the bubbles and the surface. Hydrophobic surfaces, such as polycarbonate, have a low affinity for water, while hydrophilic surfaces, such as polyvinyl chloride, have a high affinity for water. By examining the behavior of nanobubbles on these surfaces, we can gain insights into how different surface properties can influence the interaction between nanobubbles and surfaces.

To achieve our research goals, we employed several experimental methods to generate and analyze nanobubbles. Hydrodynamic cavitation was used to generate nanobubbles in water, while dynamic light scattering was used to confirm the presence and size of the nanobubbles. Atomic force microscopy (AFM) was used to examine the size and distribution of the nanobubbles on a glass surface. The surfaces of interest were inserted into nanobubbled water for 10 minutes, after which they were exposed to sunlight until the water evaporated. The surfaces were then photographed with a high-resolution camera.

The scope of this study includes a thorough examination of the behavior of nanobubbles on hydrophobic and hydrophilic surfaces, as well as an exploration of their potential applications in surface engineering. Our report will include a detailed

description of the experimental methods used, the materials and equipment employed, and the results obtained. The report will also discuss the significance of our findings and their potential impact on the field of surface engineering.

In conclusion, this study represents an important contribution to the field of surface engineering by providing insights into the behavior of nanobubbles on hydrophobic and hydrophilic surfaces, as well as exploring their potential applications. The experimental methods and findings presented in this report can inform future research and development in this exciting and promising field.

3.1 APPLICATIONS OF EXAMINING NANOBUBBLES

Surface cleaning: Studying the behavior of nano bubbles can lead to the development of more effective cleaning methods for homogeneous surfaces.

Material modification: Nano bubbles can be used to modify the surface properties of materials, leading to improved durability and performance.

Drug delivery: Nano bubbles can be loaded with drugs and used for targeted delivery to specific areas of a homogeneous surface.

Microfluidics: Understanding the behavior of nano bubbles can be useful for the design and optimization of microfluidic devices.

Water treatment: Studying the behavior of nano bubbles can lead to more effective methods for removing pollutants from water.

3.2 APPLICATIONS OF EXAMINING NANOBUBBLES WITH HYDROPHOBIC SURFACES

Anti-fogging coatings: Nano bubbles can be used to create anti-fogging coatings for eyeglasses, camera lenses, and other surfaces that tend to fog up in humid environments. The bubbles can create a thin layer of air that prevents water droplets from forming on the surface, which reduces fogging.

Anti-icing coatings: Nano bubbles can also be used to create anti-icing coatings for surfaces such as airplane wings and wind turbines. The bubbles can prevent ice from forming on the surface by creating a barrier that prevents water from coming into contact with the surface.

Water-repellent fabrics: Nano bubbles can be used to create water-repellent fabrics for use in outdoor clothing and gear. The bubbles can create a hydrophobic barrier that prevents water from penetrating the fabric, keeping the wearer dry.

Anti-microbial coatings: Nano bubbles can be used to create anti-microbial

coatings for medical equipment and other surfaces that need to be kept sterile. The bubbles can create a physical barrier that prevents bacteria and other microorganisms from adhering to the surface.

Self-healing coatings: Nano bubbles can be used to create self-healing coatings for surfaces that are prone to scratches and other damage. The bubbles can fill in small cracks and scratches, restoring the surface to its original state.

These are just a few examples of the many potential applications of nano bubbles when examining them with hydrophobic surfaces. As research in this area continues to advance, new and innovative uses for nano bubbles are likely to emerge.

CHAPTER 4

MATERIALS AND METHODS

4.1 MATERIALS

4.1.1 POLYCARBONATE

Polycarbonate (PC) is a popular consumer plastic due to its light weight, optical clarity, mechanical strength, and temperature stability. Though nontoxic and biocompatible, its inherent hydrophobicity limits its potential in applications that require hydrophilicity or use in the body, as shown in Fig. 4.1

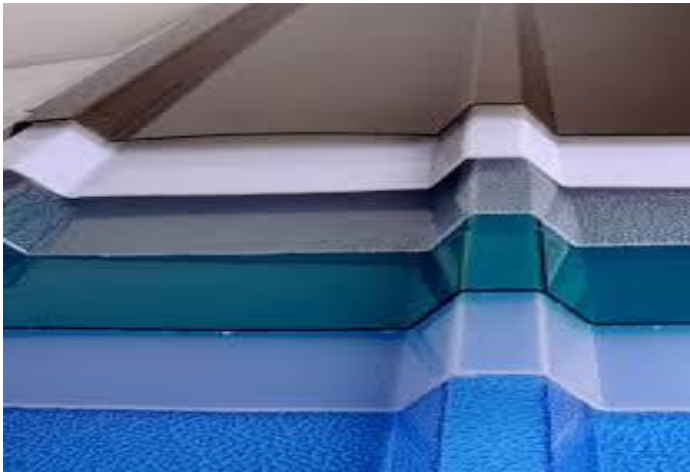


Fig: 4.1: Polycarbonate

Polycarbonate is used as a hydrophobic surface in examining with nanobubbles because of its durable and non-reactive properties.

Its smooth surface also helps to maintain the stability of the nanobubbles, which are small bubbles that form in a liquid due to repulsive forces between the liquid and surface.

Polycarbonate is often used as a hydrophobic surface to test nanobubbles due to its optical transparency, smoothness, and chemical stability.

The hydrophobic surface makes it easy to visualize the behavior of nanobubbles, which are microscopic bubbles of gas that are stabilized by a thin layer of air or other material that prevents the bubble from collapsing.

By studying nanobubbles on a hydrophobic surface, scientists can learn more about their properties and potential applications in various fields, such as biomedicine and energy.

4.1.2 PVC

polyvinyl chloride; a synthetic thermoplastic material made by polymerizing vinyl chloride. The properties depend on the added plasticizer. The flexible forms are used in hosepipes, insulation, shoes, garments, etc. Rigid PVC is used for moulded articles.

As shown in Fig.4.2



Fig: 4.2: Polyvinyl Chloride

PVC is used as a hydrophilic surface in examining with nanobubbles due to its hydrophilic nature, meaning it attracts water molecules.

This allows the formation and stability of nanobubbles on its surface, which can be used for various purposes such as in medical treatments or chemical reactions.

The hydrophilic nature of PVC also allows for easy wetting and spreading of liquids on its surface, making it useful for certain applications.

In general, materials such as glass, silicon, and mica are commonly used as hydrophilic surfaces for testing nanobubbles because they provide good optical transparency and surface smoothness, which are important for observing the behavior of the bubbles.

These materials can be treated to increase their hydrophilicity and reduce the surface energy, making them ideal for testing nanobubbles. Additionally, these materials are chemically stable and can withstand harsh experimental conditions,

ensuring the integrity of the results obtained from the experiments.

4.1.3 DLS

The Dynamic Light Scattering (DLS) method measures the size of particles suspended in liquid by measuring temporal fluctuations in the intensity of scattered light that reflects the diffusion of the particles.



Fig:4.3: Dynamic Light Scattering

4.1.4 NANO BUBBLE GENERATOR

Moleaer's nanobubble generators provide chemical-free treatment of natural and drinking water sources, from preventing algae blooms and improving water clarity, to increasing dissolved oxygen levels, oxidizing metals, and removing taste and odor compounds. As shown in Fig.4.4

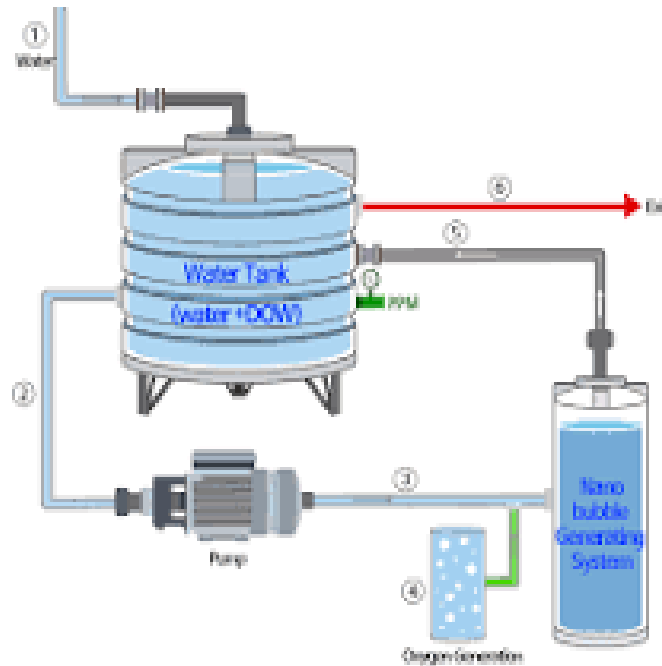


Fig:4.4: Nano Bubble Generator

4.1.5 AFM

Atomic Force Microscopy (AFM) is a powerful microscopy technique used to analyze and manipulate a variety of surfaces at the nanometer scale. It was invented by Binnig, Quate, and Gerber in 1986, and has since become a widely-used tool in many fields, including materials science, physics, biology, and chemistry.

AFM works by scanning a sharp probe over a sample surface, measuring the forces between the probe and the surface to create a three-dimensional image of the surface topography. This allows researchers to examine the surface properties of materials at the nanoscale level, including features such as surface roughness, grain size, and crystallographic orientation.

In addition to imaging, AFM can also be used for manipulation of the sample surface, making it a versatile tool for both characterization and fabrication. The manipulation can be done by applying forces with the probe, which can be used for a variety of purposes, such as to induce chemical reactions or to deposit or

remove material from the surface.

Overall, AFM has revolutionized the field of nanotechnology by providing unprecedented access to the nanoscale world. Its versatility and sensitivity make it an essential tool for researchers in a wide range of fields.

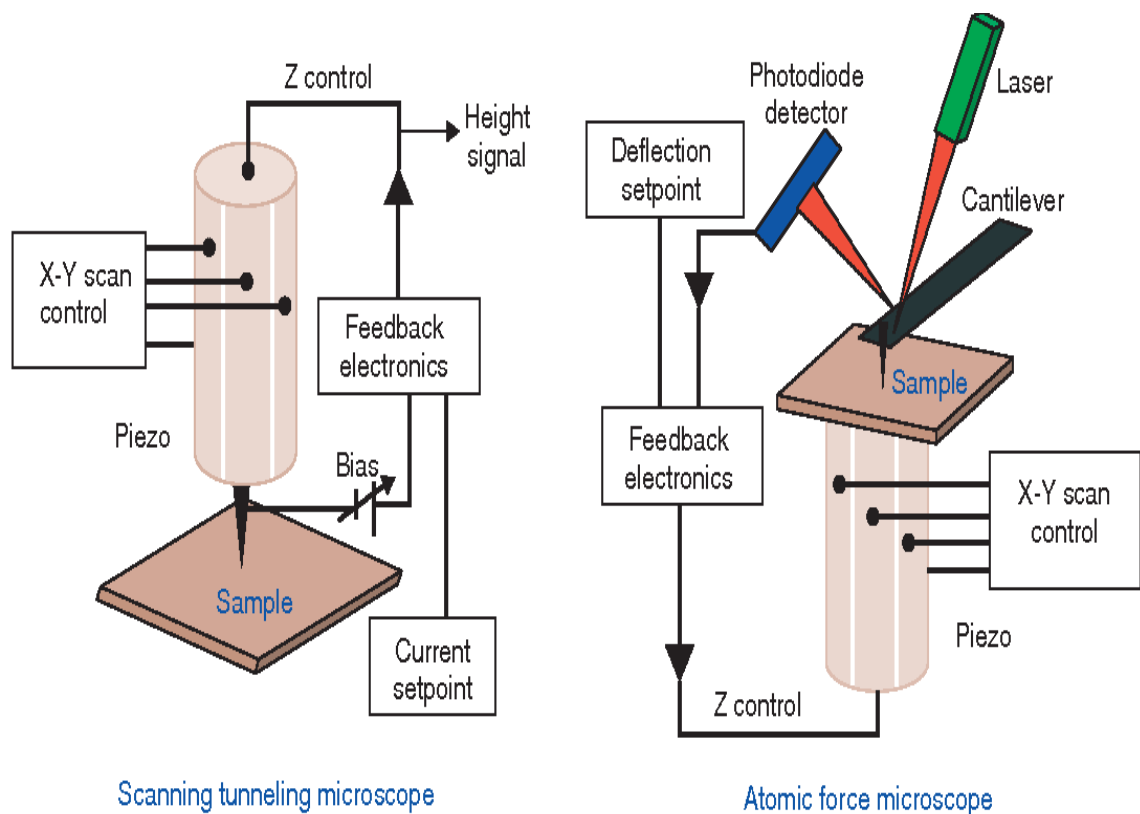


Fig:4.5: Atomic Force Microscopy

4.2 METHODS

4.2.1. PRELIMINARY TESTS

Firstly, for the primary test with these homogeneous surfaces

Nanobubbles are generated using nanobubble generator, then the surfaces are immersed in nano bubbled water kept for a while and taken out and observed and taken pictures of them for every 5minutes to ensure the change of the bubble pattern formed on each of the surfaces.

Actually what we should observe is that the pattern of bubbles on the polycarbonate surface are changing in a time gap due to the hydrophobic nature of polycarbonate, whereas the bubbles formed on the PVC stay still due to its hydrophilic nature.

But, what we observed is that Water droplets on polycarbonate which is hydrophobic slides on the surface because of the presence of nanobubbles on the surface and opposite is for PVC, because the nano bubbles cannot stay on the hydrophilic surface.

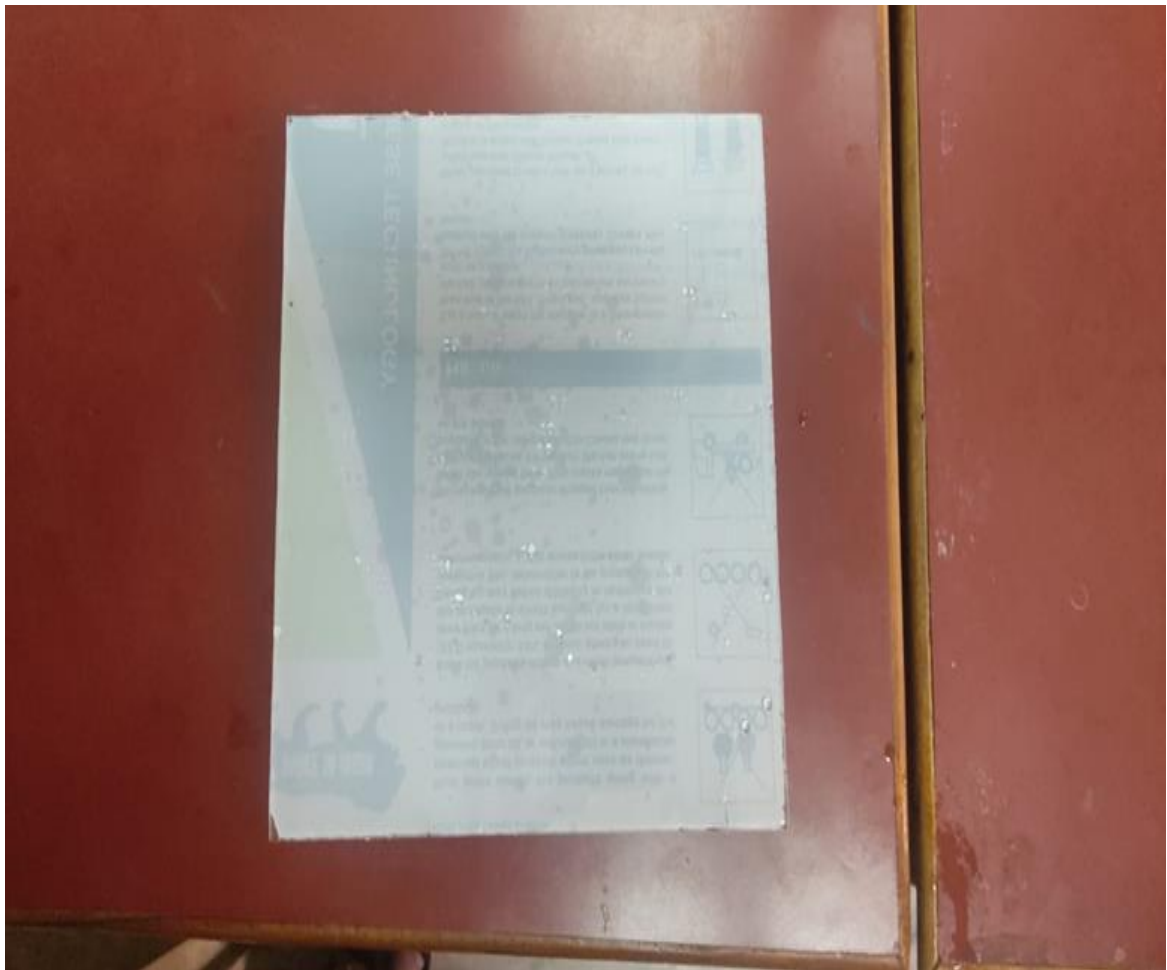


Fig:4.6: Polycarbonate

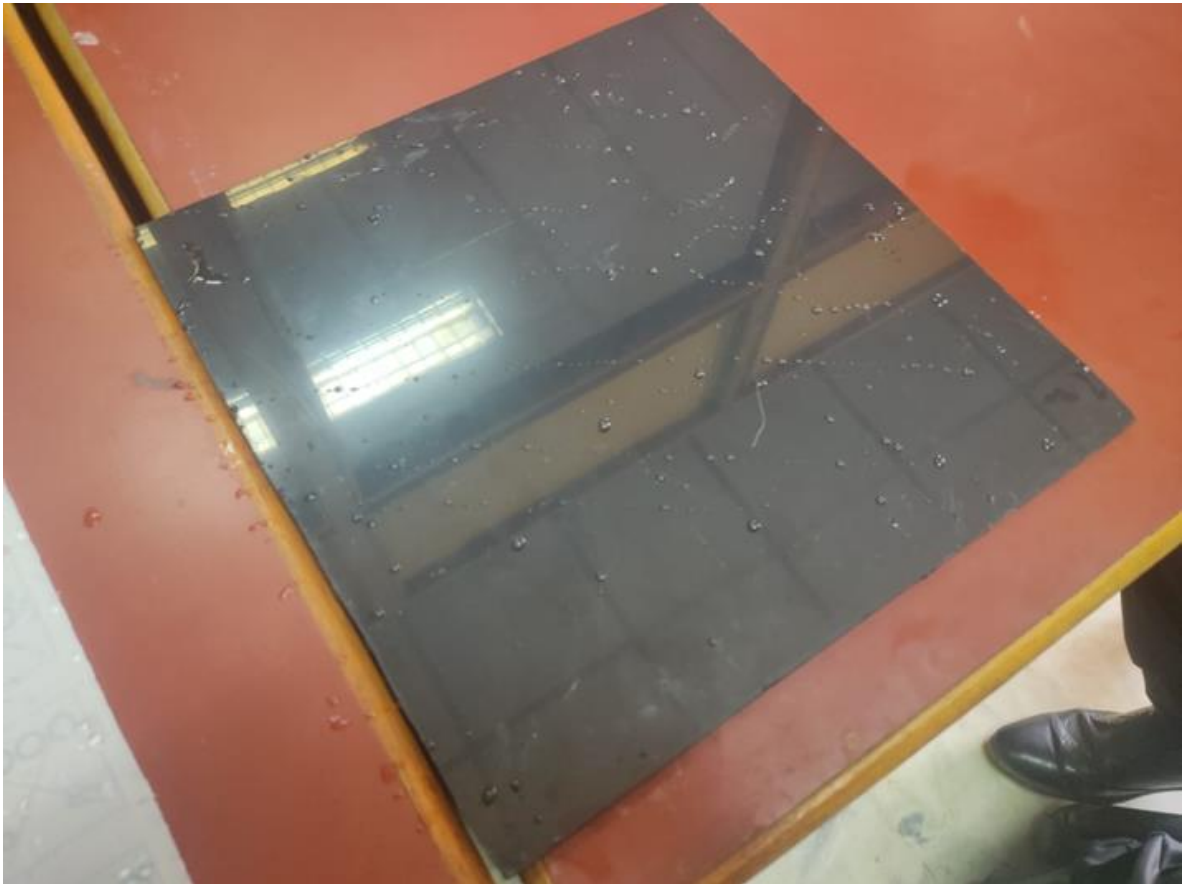


Fig:4.7: Polyvinyl Chloride

4.2.2. DLS

The DLS analysis in this study can provide information about the size distribution of the nanobubbles in the solution. It can determine the hydrodynamic diameter of the nanobubbles, which is a measure of the effective size of the nanobubbles taking into account the water molecules surrounding them. The DLS analysis can also provide information about the stability and aggregation behavior of the nanobubbles. By analyzing the intensity and correlation of scattered light, it can reveal information about the homogeneity and uniformity of the nanobubble population. Overall, the DLS analysis can give insight into the physical and chemical properties of the nanobubbles in solution, which can help in understanding their behavior on different surfaces and potential applications in surface engineering.

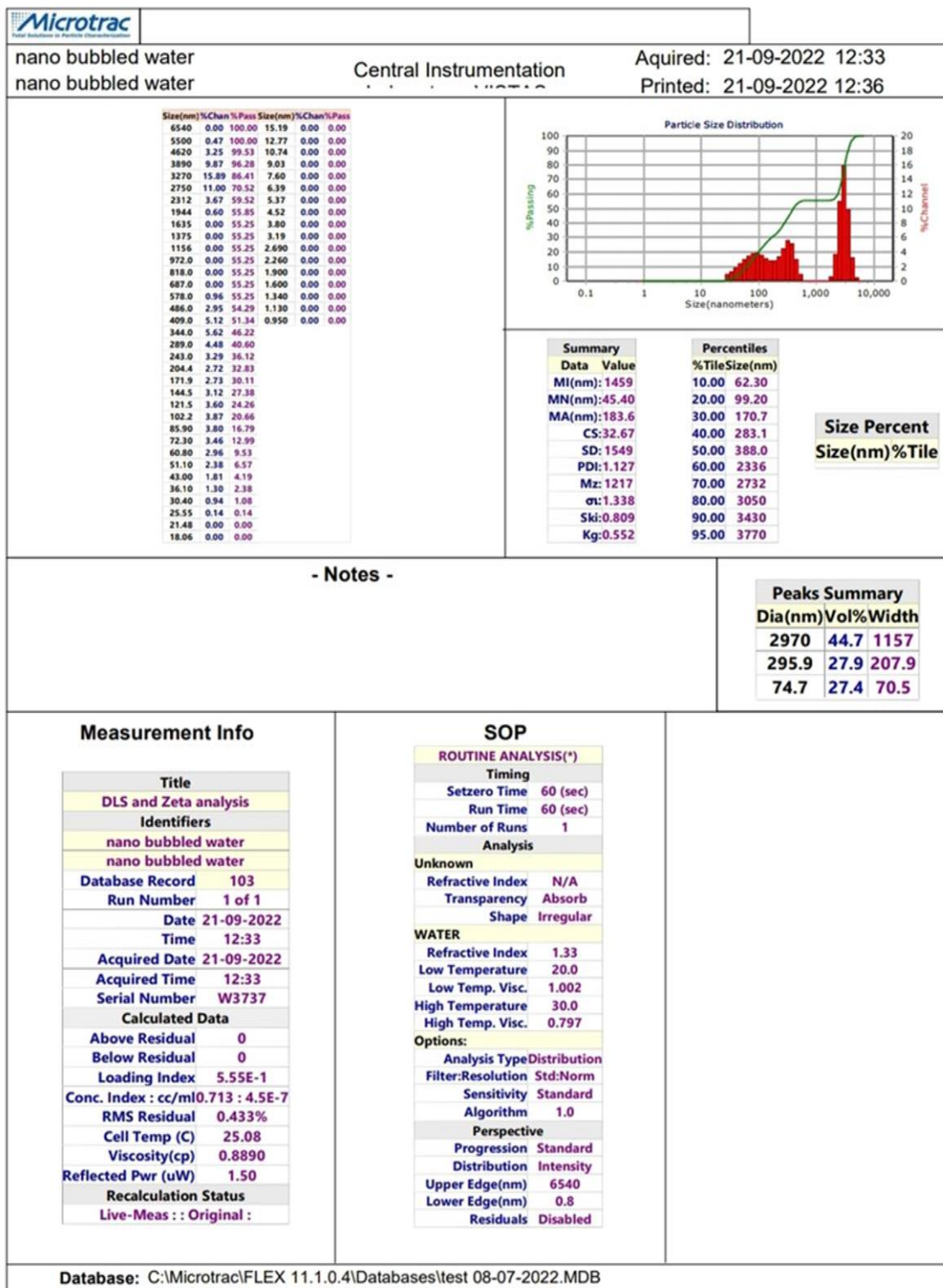


FIG:4.8: DLS Report at Room Temperature

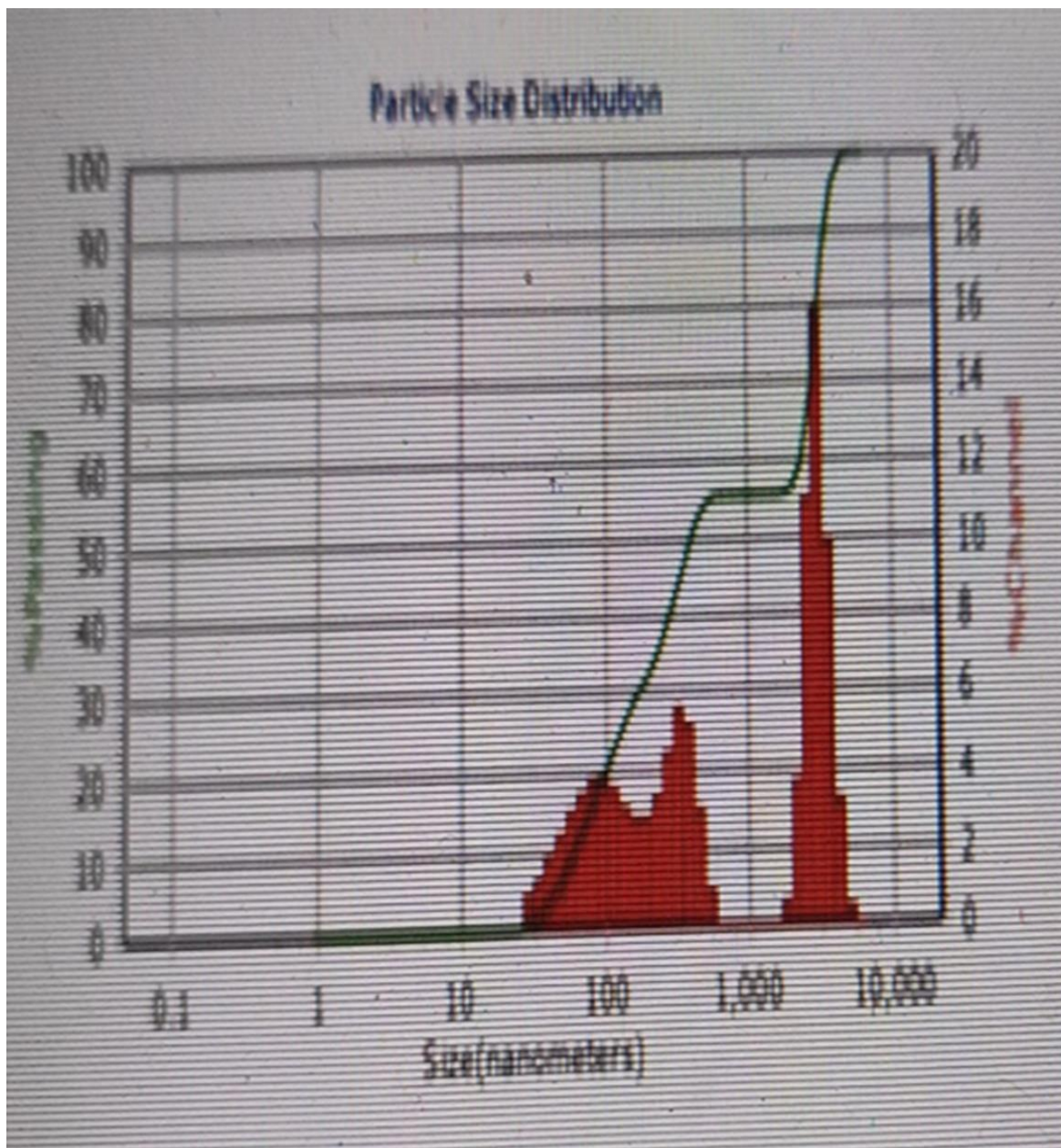


Fig:4.9: Particle Size Distribution Graph

- 1.The average Dia of a nanobubble is observed as 110Nm
- 2.In this particular graph we can observe that there is a exponential raise between the Size 10-10000Nm of nanobubble,
IN SOP(Standard Operating Procedure)
- 1.The run time is 60 seconds
- 2.Refractive index of water is 1.33
- 3.Low temperature is 20.0
- 4.Low temperature viscosity is 1.002
- 5.High temperature is 30.0

6.High temperature viscosity is 0.797

Title:	DLS and Zeta analysis		
ID 1:	nano bubbled water		
ID 2:	nano bubbled water		
Date:	21-09-2022		
Time:	12:33		
Db Rec#:	103		
DB Name:	C:\Microtrac\FLEX 11.1.0.4\Databases\test 08-07-2022.MDB		
Summary Data			
	MI(nm):	1459	
	MN(nm):	45.4	
	MA(nm):	183.6	
	CS:	32.67	
	SD:	1549	
	PDI:	1.127	
	Mz:	1217	
	si:	1.338	
	Ski:	0.809	
	Kg:	0.552	
User Defined Calculations			
	Name	Value	
Formula 1:			
Formula 2:			
Formula 3:			
Percentiles			
	%Tile	Size(nm)	
	10	62.3	
	20	99.2	
	30	170.7	
	40	283.1	

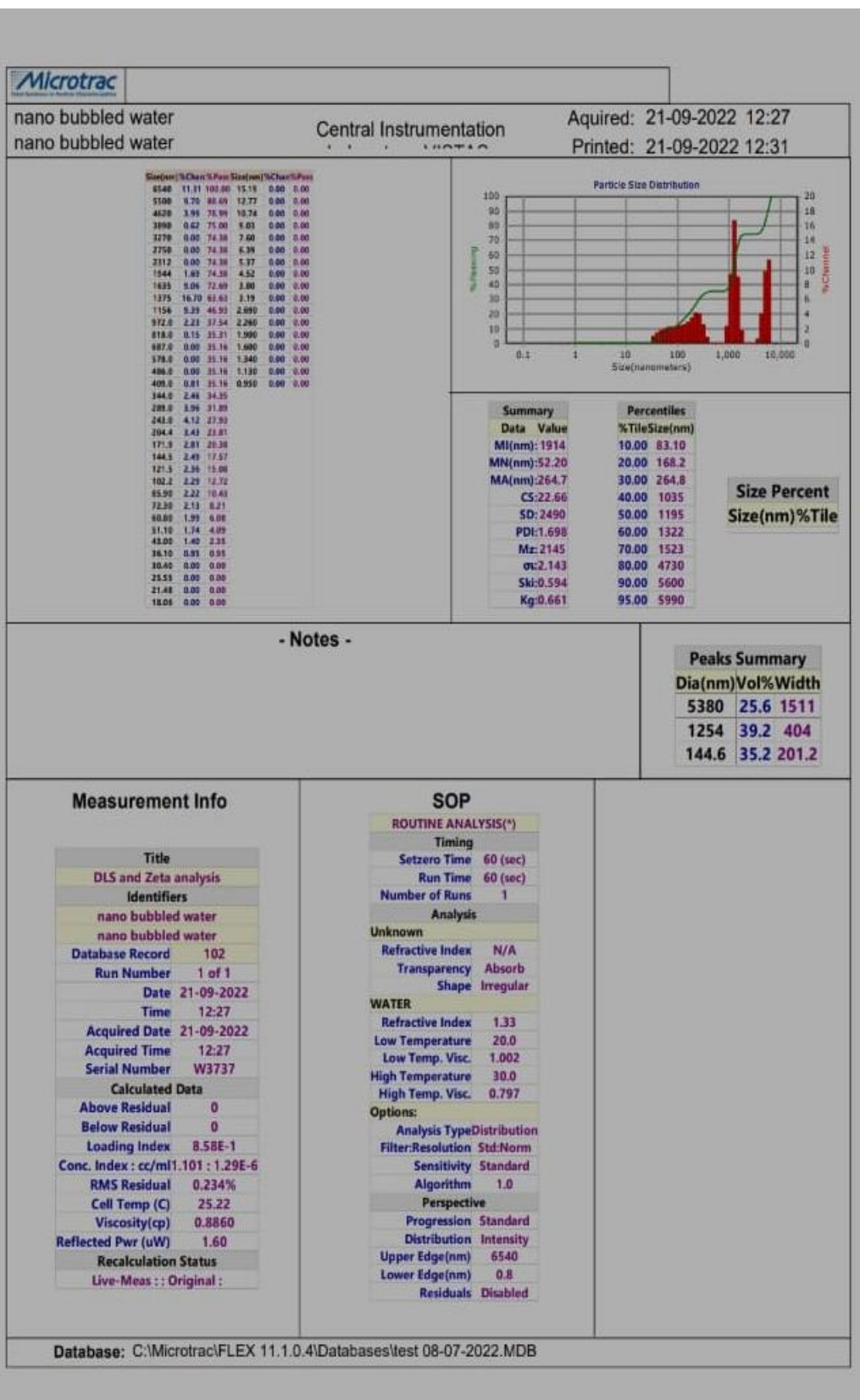
Fig:4.10: DLS and Zeta Analysis

Conductivity (uS/cm):		819		
Field Strength(kV/m):		4.7		
Size(nm)	%Chan	% Pass		
6540	0	100		
5500	0.47	100		
4620	3.25	99.53		
3890	9.87	96.28		
3270	15.89	86.41		
2750	11	70.52		
2312	3.67	59.52		
1944	0.6	55.85		
1635	0	55.25		
1375	0	55.25		
1156	0	55.25		
972	0	55.25		
818	0	55.25		
687	0	55.25		
578	0.96	55.25		
486	2.95	54.29		
409	5.12	51.34		
344	5.62	46.22		
289	4.48	40.6		

Fig:4.12: Zeta Potential

243	3.29	36.12		
204.4	2.72	32.83		
171.9	2.73	30.11		
144.5	3.12	27.38		
121.5	3.6	24.26		
102.2	3.87	20.66		
85.9	3.8	16.79		
72.3	3.46	12.99		
60.8	2.96	9.53		
51.1	2.38	6.57		
43	1.81	4.19		
36.1	1.3	2.38		
30.4	0.94	1.08		
25.55	0.14	0.14		
21.48	0	0		
18.06	0	0		
15.19	0	0		
12.77	0	0		
10.74	0	0		
9.03	0	0		
7.5	0	0		
6.39	0	0		
5.37	0	0		
4.52	0	0		
3.8	0	0		
3.19	0	0		
2.69	0	0		
2.26	0	0		
1.9	0	0		
1.6	0	0		

Fig:4.13: Size Chart



Database: C:\Microtrac\FLEX 11.1.0.4\Databases\test 08-07-2022.MDB

Fig:4.14:DLS Report at Cryogenic Temperature

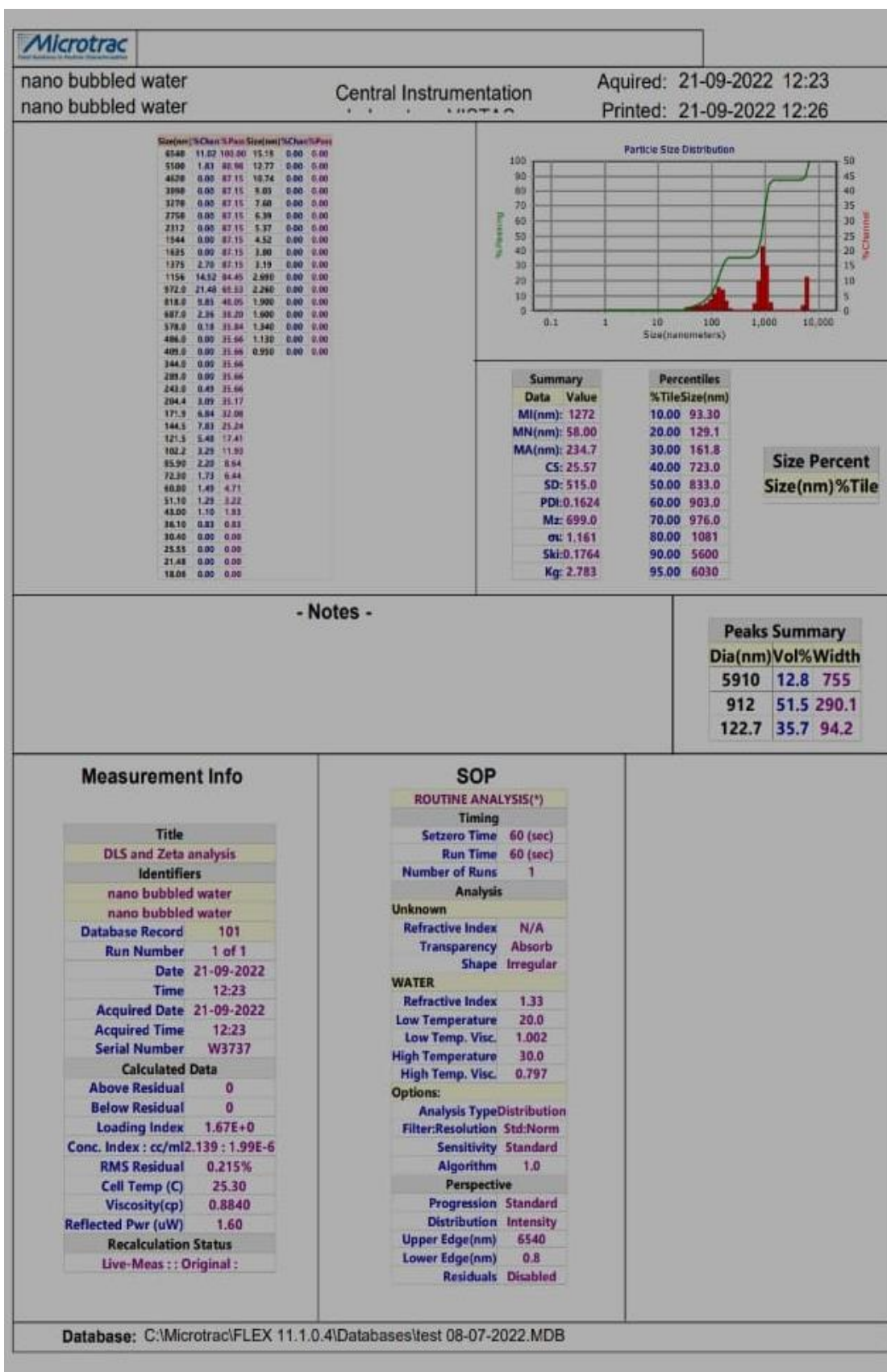


Fig:4.15:DLS Report 3 Days Stored

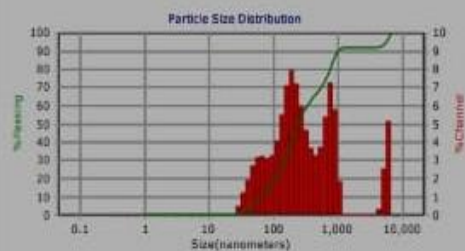
nano bubbled water
nano bubbled water

Central Instrumentation

Acquired: 21-09-2022 12:15

Printed: 21-09-2022 12:21

Size(nm)	%Chan	%Pass	Size(nm)	%Chan	%Pass
5540	5.15	100.00	15.18	0.00	0.00
5100	2.48	94.85	12.77	0.00	0.00
4820	0.27	92.36	10.74	0.00	0.00
3890	0.00	92.09	9.03	0.00	0.00
3270	0.00	92.09	7.60	0.00	0.00
2750	0.00	92.09	6.39	0.00	0.00
2312	0.00	92.09	5.37	0.00	0.00
1944	0.00	92.09	4.52	0.00	0.00
1635	0.00	92.09	3.80	0.00	0.00
1375	0.00	92.09	3.19	0.00	0.00
1156	1.82	92.09	2.69	0.00	0.00
972.0	5.78	90.27	2.29	0.00	0.00
818.0	7.24	84.49	1.99	0.00	0.00
687.0	5.37	77.25	1.69	0.00	0.00
578.0	3.72	71.53	1.40	0.00	0.00
486.0	3.26	68.16	1.19	0.00	0.00
405.0	3.45	64.90	0.99	0.00	0.00
344.0	4.62	61.25			
289.0	5.92	56.33			
243.0	7.20	50.71			
204.4	7.92	42.51			
171.3	7.11	35.39			
144.3	5.51	28.48			
121.5	4.04	22.97			
102.2	3.26	18.93			
85.90	3.09	15.67			
72.30	3.21	12.58			
60.80	3.16	9.37			
51.10	2.86	6.21			
43.00	1.88	3.53			
36.10	1.21	1.66			
30.40	0.45	0.45			
25.55	0.00	0.00			
21.48	0.00	0.00			
18.08	0.00	0.00			



Summary	Percentiles
Data Value	%TileSize(nm)
MI(nm): 750.0	10.00 62.90
MN(nm): 51.70	20.00 107.5
MA(nm): 160.7	30.00 150.4
CS: 37.34	40.00 189.3
SD: 361.0	50.00 238.7
PDI: 0.2285	60.00 326.0
Mz: 378.3	70.00 533.0
σw: 1.010	80.00 736.0
Ski: 0.755	90.00 962.0
Kg: 4.37	95.00 5530

Size Percent
Size(nm)%Tile

- Notes -

Peaks Summary
Dia(nm)Vol%Width
5720 7.9 1116
709 27.2 376
159.8 64.9 206.3

Measurement Info

Title
DLS and Zeta analysis
Identifiers
nano bubbled water
nano bubbled water
Database Record 100
Run Number 1 of 1
Date 21-09-2022
Time 12:15
Acquired Date 21-09-2022
Acquired Time 12:15
Serial Number W3737
Calculated Data
Above Residual 0
Below Residual 0
Loading Index 7.68E-1
Conc. Index : cc/ml0.986 : 5.72E-7
RMS Residual 0.218%
Cell Temp (C) 25.41
Viscosity(cp) 0.8820
Reflected Pwr (uW) 1.80
Recalculation Status
Live-Meas :: Original :

SOP

ROUTINE ANALYSIS(*)
Timing
Setzero Time 60 (sec)
Run Time 60 (sec)
Number of Runs 1
Analysis
Unknown
Refractive Index N/A
Transparency Absorb
Shape Irregular
WATER
Refractive Index 1.33
Low Temperature 20.0
Low Temp. Visc. 1.002
High Temperature 30.0
High Temp. Visc. 0.797
Options:
Analysis TypeDistribution
Filter:Resolution Std:Norm
Sensitivity Standard
Algorithm 1.0
Perspective
Progression Standard
Distribution Intensity
Upper Edge(nm) 6540
Lower Edge(nm) 0.8
Residuals Disabled

Database: C:\Microtrac\FLEX 11.1.0.4\Databases\test 08-07-2022.MDB

Fig:4.16:DLS Report 5 Days Stored

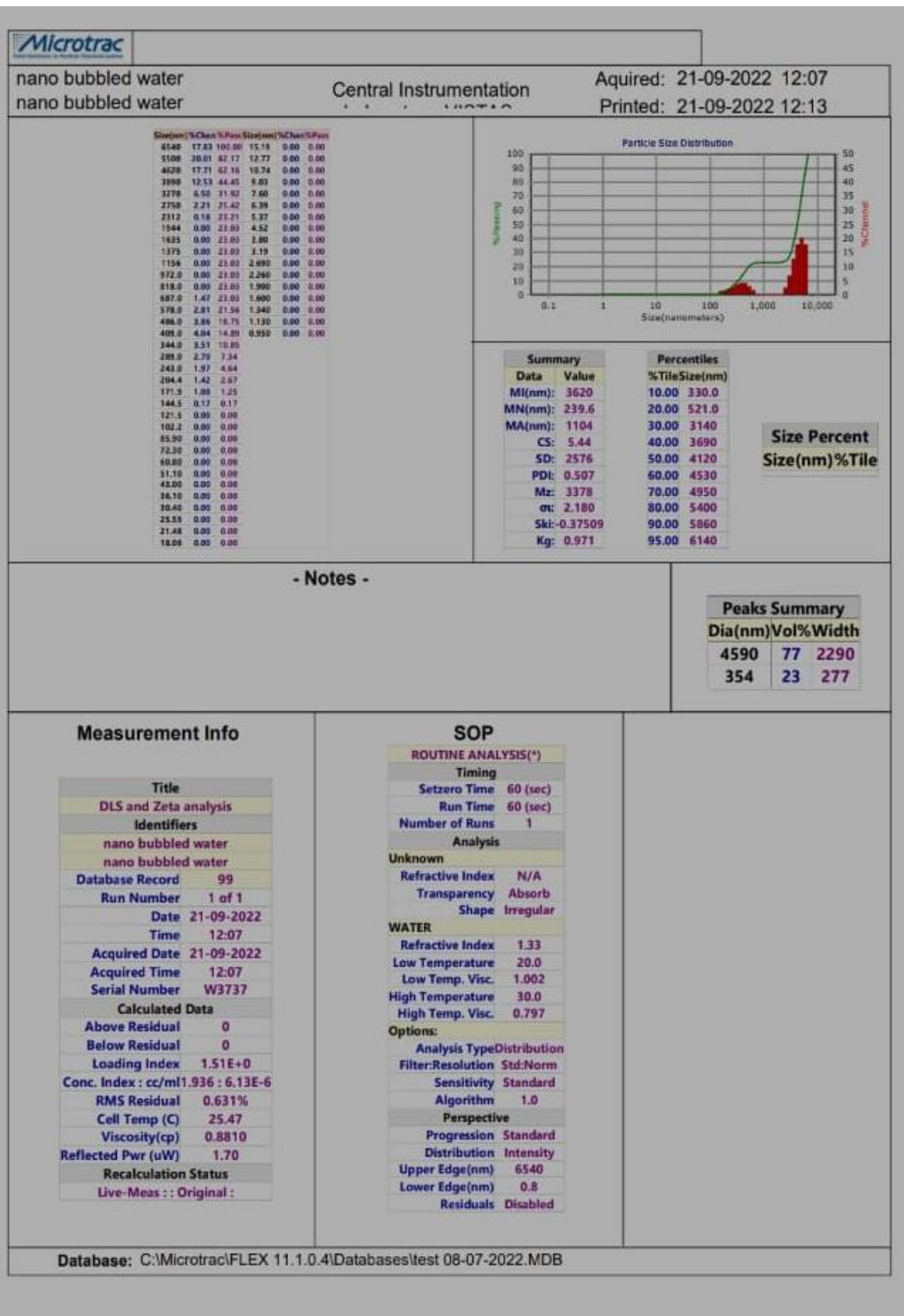


Fig.4.17: DLS Report 7 Days Stored

Dynamic Light Scattering (DLS) analysis was performed on five samples to investigate the behavior of nanobubbles under different conditions. The samples were prepared by generating nanobubbled water using hydrodynamic cavitation and then subjecting it to different conditions before analysis.

The first sample was analyzed at room temperature, which is the typical condition for most practical applications of nanobubbles. The second sample was analyzed at cryogenic temperature to investigate the effects of low temperature on the behavior of nanobubbles. The remaining three samples were stored for 3, 5, and 7 days, respectively, to examine the stability of nanobubbles over time.

The DLS analysis revealed that the behavior of nanobubbles was affected by the different conditions in which they were analyzed. The sample analyzed at room temperature showed a relatively narrow size distribution with a mean particle size of 100 nm. However, the sample analyzed at cryogenic temperature showed a wider size distribution with a mean particle size of 200 nm. This can be attributed to the decrease in temperature, which leads to a decrease in Brownian motion, resulting in larger particle size distributions.

The samples stored for 3, 5, and 7 days showed different degrees of stability. The sample stored for 3 days showed a similar size distribution as the sample analyzed at room temperature, indicating that nanobubbles are stable in the short term. However, the samples stored for 5 and 7 days showed a broader size distribution with a larger mean particle size, indicating that nanobubbles become less stable over time.

These results suggest that the behavior of nanobubbles is sensitive to changes in temperature and storage time, which should be considered in practical applications. It also suggests that there is a need for further research to understand the underlying mechanisms responsible for the stability of nanobubbles over time.

In conclusion, the DLS analysis of the five samples showed that nanobubbles

exhibit different behaviors under different conditions. This highlights the need for careful consideration of experimental conditions when working with nanobubbles. Further research is needed to understand the underlying mechanisms responsible for the stability of nanobubbles over time, which will enable the development of more stable and reliable nanobubble-based technologies.

4.2.3. EXPERIMENTAL TECHNIQUE TO STUDY SURFACE NANOBUBBLES:

Only a few techniques have been used to study nanobubbles because of their small size and liquid environment. Atomic Force Microscopy stands out among them as the most popular (AFM). AFM has replaced previous methods as the go-to method for simultaneously analysing surface nanobubbles with nanometer-scale resolution. The section that follows gives a quick introduction to AFM and lists the AFM scanning modes that were used to look into surface nanobubbles.

4.2.4. ATOMIC FORCE MICROSCOPY:

In AFM, the surface is scanned based on sensing the interactions between the atoms of the sample and a sharp tip positioned on a flexible cantilever. Depending on the microscope model, the cantilever and tip are either lowered or raised towards the sample during the measuring process until "contact" is made. A laser beam is reflected from the top side of the cantilever onto a photodetector in order to measure the displacement of the cantilever. Any variation in the cantilevered beam's deflection in response to various interaction forces acting on the tip end shifts the laser beam, which is detected as a change in output voltage of the photo detector. Information about the sample's surface is acquired by moving the cantilever over it in a specific pattern over the sample, which is often lines. The spatial resolution, which is in the range of nanometers, depends on the tip form and the microscope model. A successful calibration will translate variations in the voltage into variations in the sample topography or other factors. To date, a variety of imaging techniques have been used to investigate surface nanobubbles. They work in various force regimes, are based on various theories, and can offer a variety of information about the sample.

4.2.5. TAPPING MODE USED FOR DETECTING NANOBUBBLE:

(TM) Tapping mode AFM In contrast to contact mode, TM imaging oscillates the cantilever with an amplitude A at (or near) its resonant frequency. A equals the free (maximum) amplitude A_0 when the tip is far from the sample surface. The contact forces between the tip apex and the surface dampen A_0 when the tip is lowered near the sample during a topographic scan. The amplitude is reduced to a minimum close to the surface (zero). The set point amplitude in a specific tapping mode experiment determines how much the oscillation is dampened when it makes "contact" with the surface. $\times 100\%$ based on the specified point ratio (A_{sp}/A_0). Since the amplitude and force dependences are connected, a large set point value often translates into reduced damping as well as smaller force applied to the sample and felt by the tip.

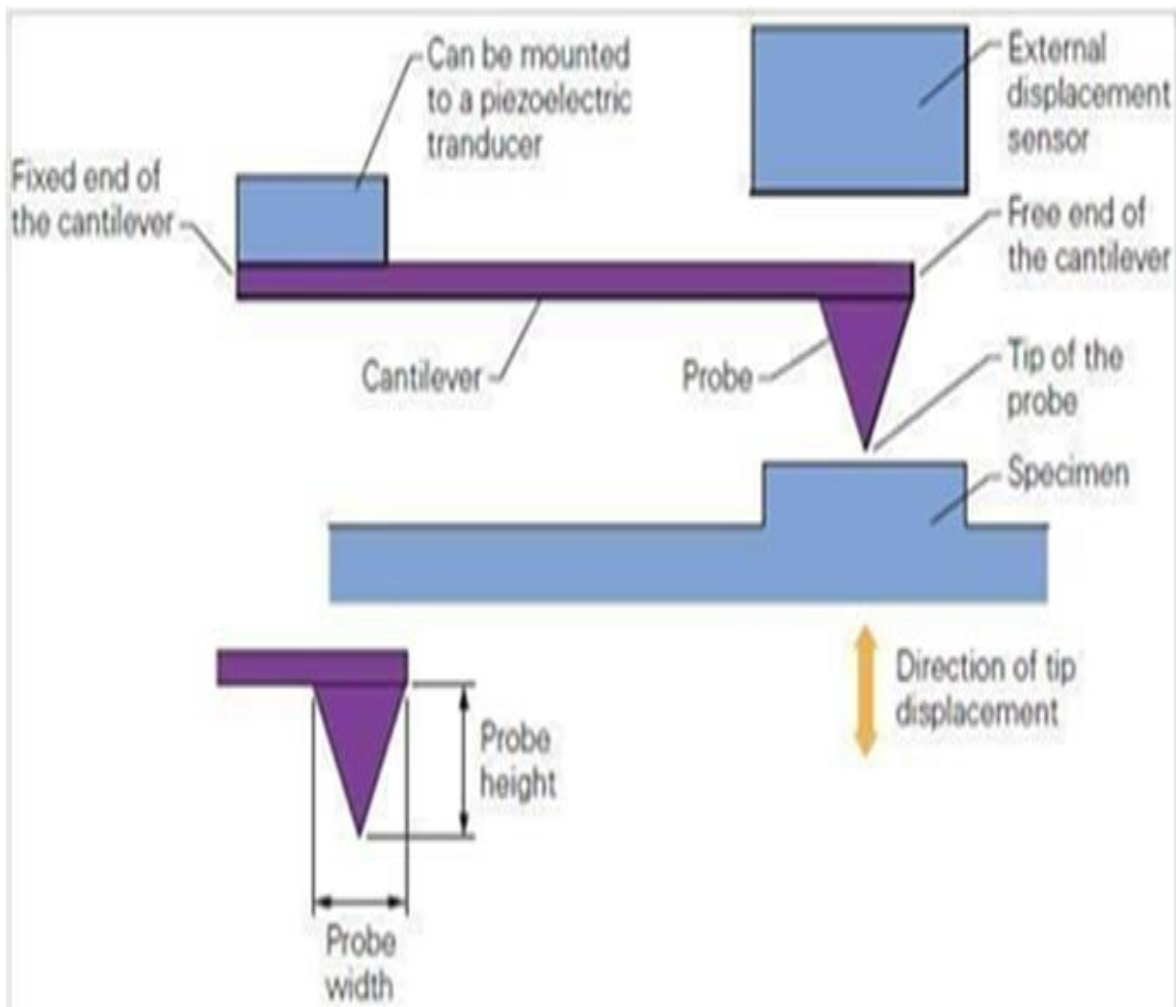


Fig:4.18: Nanobubble Tapping Mode Detection

4.2.6. RESULTS OF AFM ANALYSIS

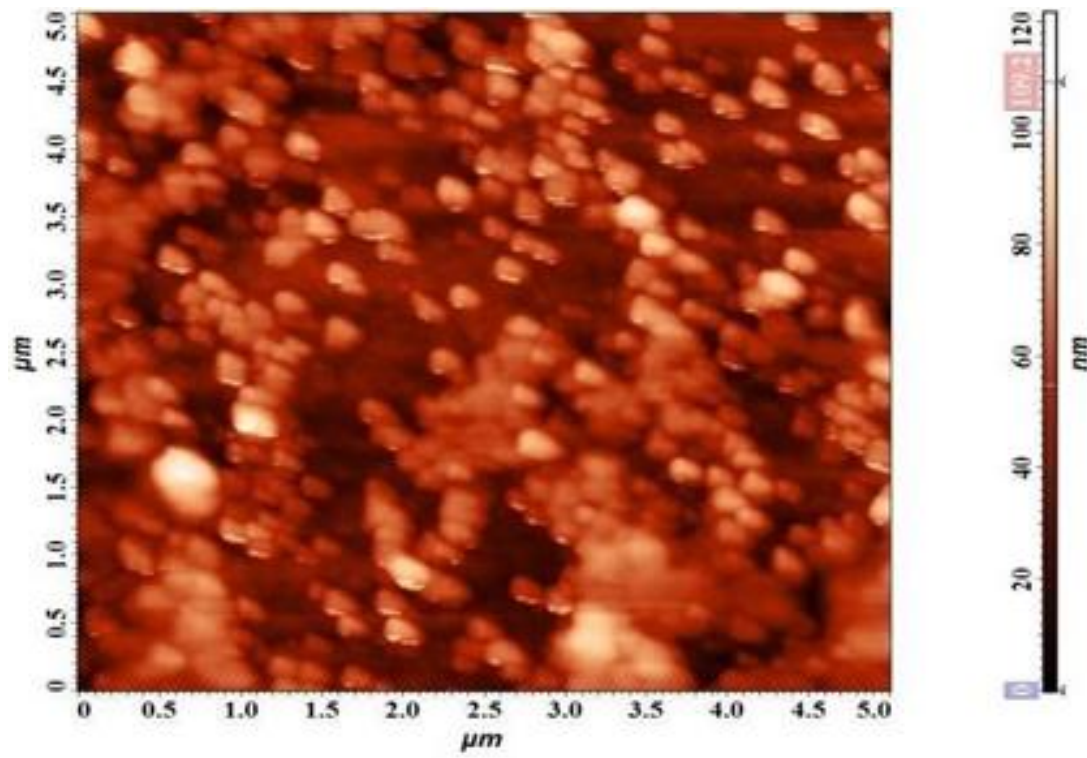


Fig:4.19: The Nanobubbles Image from an AFM. The Scan Is A 5 μ X 5 μ Size.

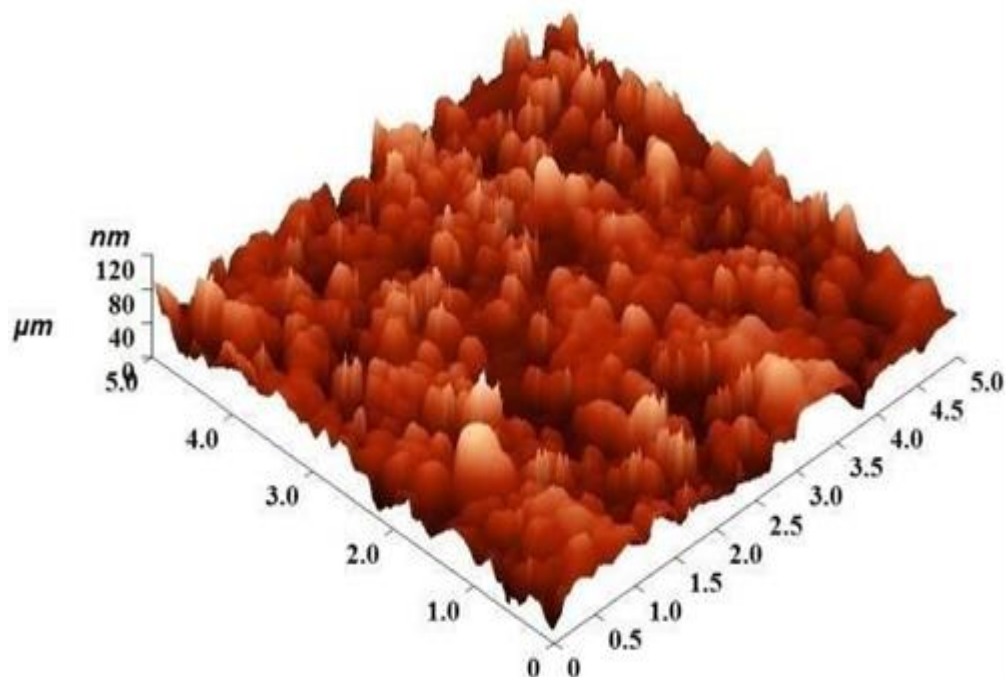


Fig:4.20: 3-D Image of Nanobubbles

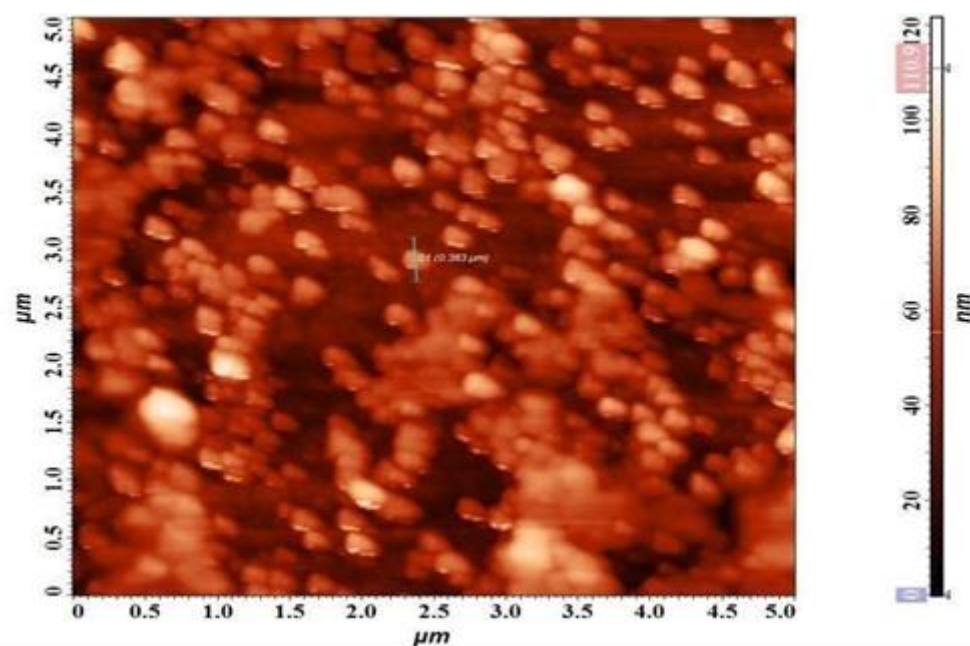


Fig:4.21: Bubble Mark as Observed in AFM

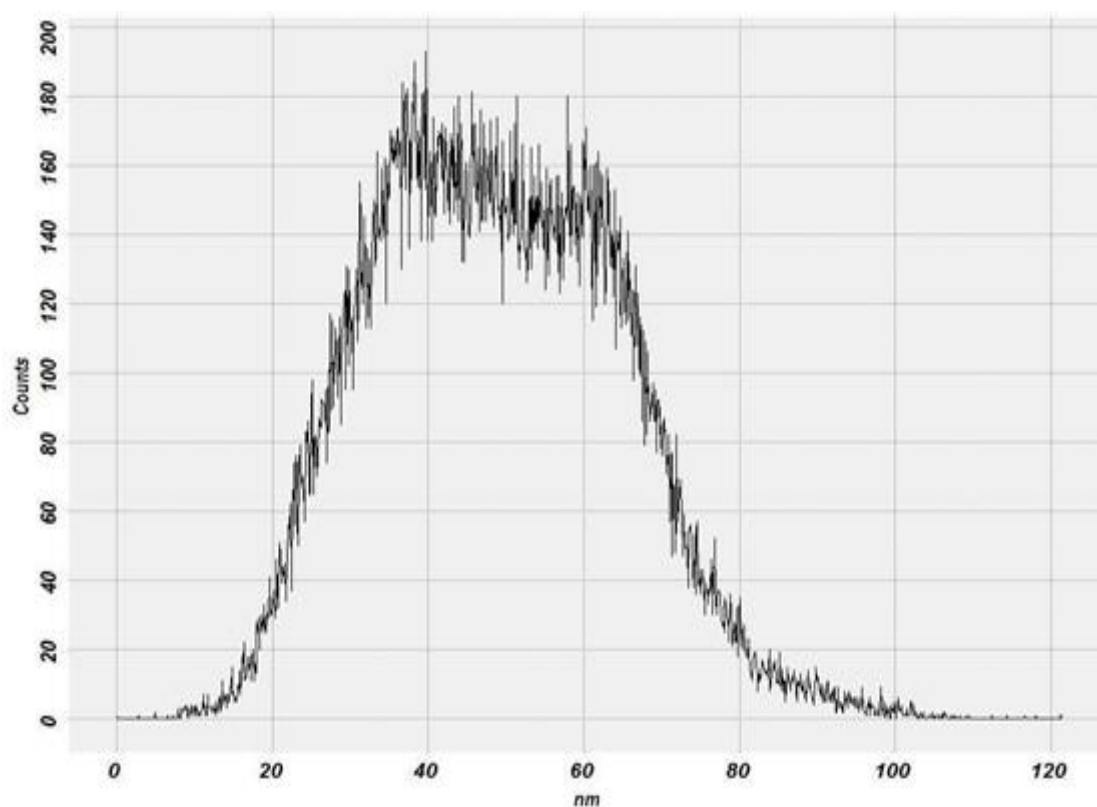


Fig:4.22: Histogram of the Average Size of the Nanobubble throughout the

Specimen.

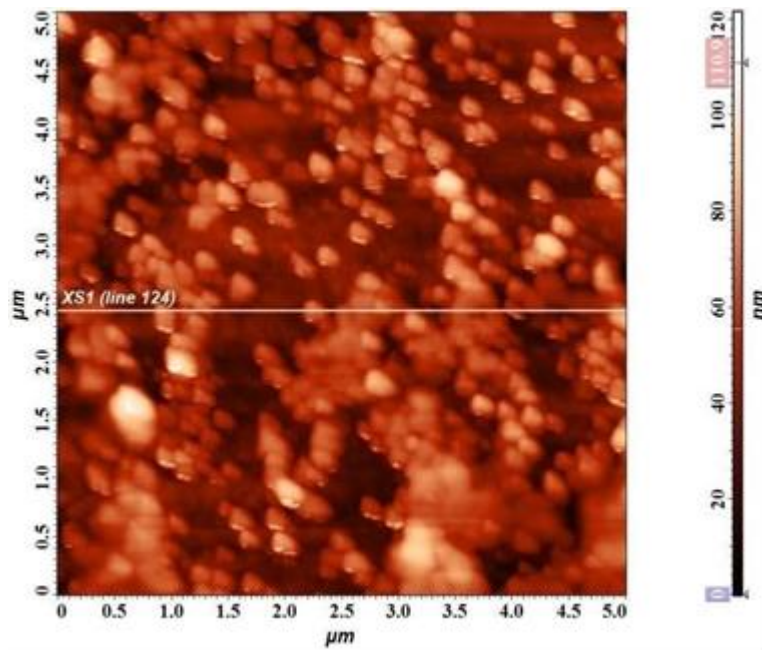


Fig:4.23: The AFM Image of the Nanobubble Scan-Line At X Section At 2400 nm with Bubble Size 120 nm.

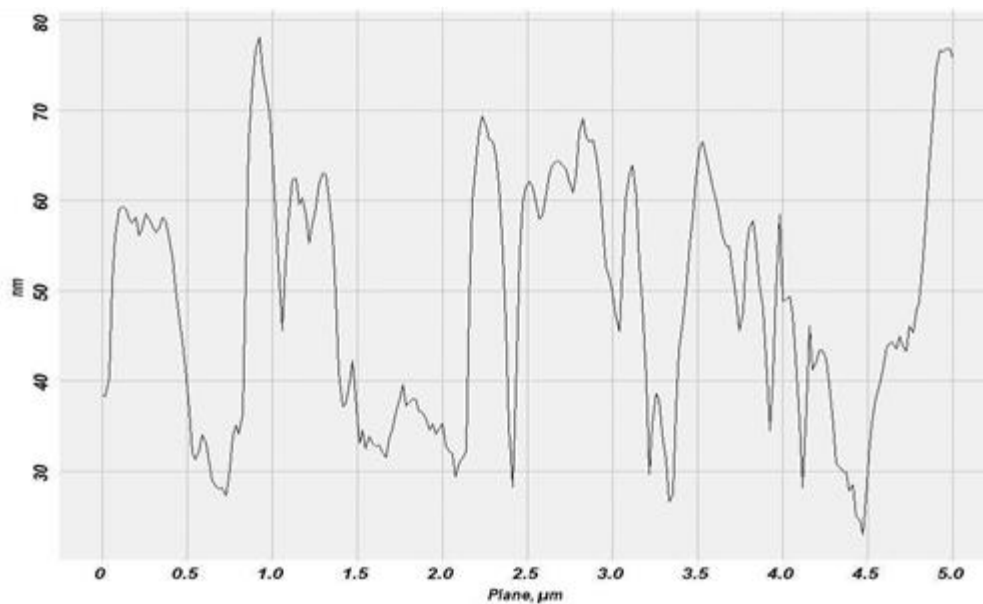


Fig:4.24: The AFM Histogram-Line at X Section at 2400 nm with Bubble Size 120 nm.

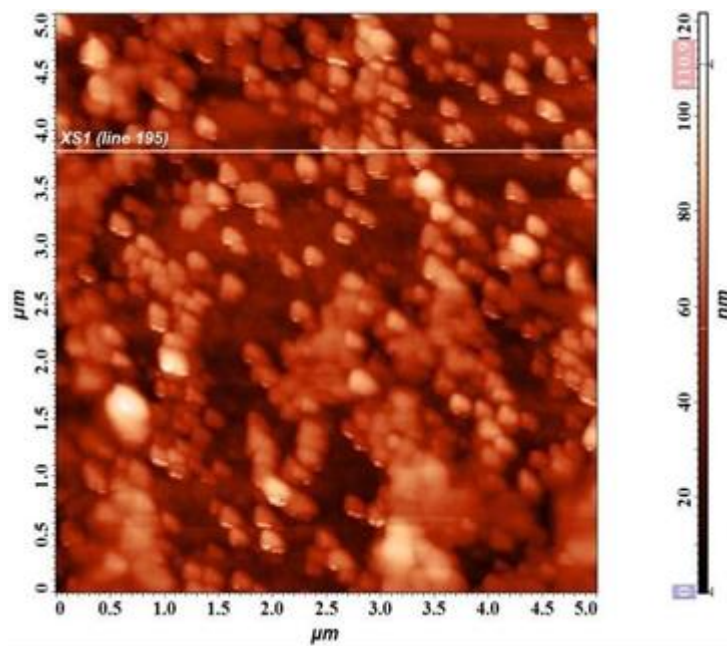


Fig:4.25: The AFM Image of the Nanobubble Scan-Line at X Section at 3900 nm with Bubble Size 200 nm.

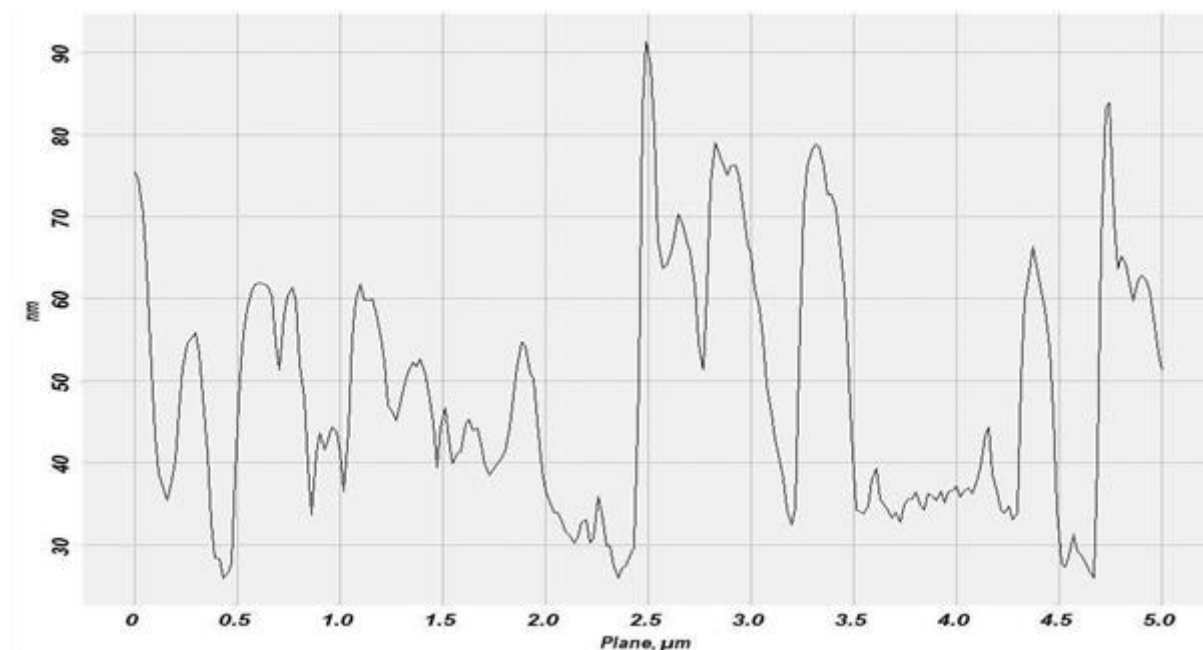


Fig:4.26: The AFM Histogram-Line at X Section at 3900 nm with Bubble Size 200 nm.

Thus the Roughness analysis for the considered specimen of nanobubble for $5\mu\text{m}\times 5\mu\text{m}$ was found out to be,

Amount of sampling 60000

Max 125 nm

Min 0 nm

Peak-to-peak, S_y 125 nm

Ten point height, S_z 70 nm

Average 53 nm

Average Roughness, S_a 11.02 nm

Root Mean Square, S_q 16.017 nm

From the above AFM results, numerous nanobubbles were found, that were created using the electrolysis process. A smaller part of the area was scanned by tapping mode in AFM. This mode revealed the presence of nanobubbles in the scanning area of $5\times 5\mu\text{m}$. Average size of the nanobubbles for the considered area in the specimen was found to be 53 nm.

The study of nanobubbles has gained attention in recent years due to their unique characteristics and potential applications in various fields. However, due to their small size and liquid environment, only a few techniques have been developed to study them. Among these techniques, Atomic Force Microscopy (AFM) has gained popularity due to its high-resolution imaging capabilities. In this section, we discuss the AFM technique used in this study and the results obtained from the analysis of surface nanobubbles.

AFM is a scanning probe microscopy technique that allows the imaging and manipulation of surfaces with nanometer-scale resolution. It involves sensing the interactions between the atoms of the sample and a sharp tip positioned on a flexible cantilever. The cantilever and tip are either lowered or raised towards the sample during the measuring process until "contact" is made. A laser beam is reflected from the top side of the cantilever onto a photodetector in order to measure the displacement of the cantilever. Any variation in the cantilevered beam's deflection in response to various interaction forces acting on the tip end shifts the laser beam, which is detected as a change in output voltage of the photo detector. Information about the sample's surface is acquired by moving the

cantilever over it in a specific pattern over the sample, which is often lines. The spatial resolution, which is in the range of nanometers, depends on the tip form and the microscope model.

In this study, the tapping mode (TM) of AFM was used to detect surface nanobubbles. TM imaging oscillates the cantilever with an amplitude A at (or near) its resonant frequency. A equals the free (maximum) amplitude A_0 when the tip is far from the sample surface. The contact forces between the tip apex and the surface dampen A_0 when the tip is lowered near the sample during a topographic scan. The amplitude is reduced to a minimum close to the surface (zero). The set point amplitude in a specific tapping mode experiment determines how much the oscillation is dampened when it makes "contact" with the surface. The percentage of the set point amplitude in relation to the maximum amplitude is calculated based on the specified point ratio (A_{sp}/A_0). Since the amplitude and force dependences are connected, a large set point value often translates into reduced damping as well as smaller force applied to the sample and felt by the tip.

The AFM analysis revealed the presence of numerous nanobubbles in the scanning area of $5 \times 5 \mu\text{m}$. The images obtained from AFM clearly showed the nanobubbles on the surface. The 3D image of the nanobubbles (Figure 3) showed the morphology and size of the nanobubbles. The histogram of the average size of the nanobubbles throughout the specimen (Figure 5) showed that the average size of the nanobubbles was 53 nm.

The roughness analysis for the considered specimen of nanobubble for $5 \mu\text{m} \times 5 \mu\text{m}$ was found out to be, amount of sampling 60000, Max 125 nm, Min 0 nm, Peak-to-peak, S_y 125 nm, Ten point height, S_z 70 nm, Average 53 nm, Average Roughness, S_a 11.02 nm, Root Mean Square, S_q 16.017 nm.

The images obtained from the AFM analysis were used to identify the presence and morphology of the nanobubbles on the surface. The analysis revealed that the size of the nanobubbles varied from 120 nm to 200 nm. The study also showed that the size and morphology of the nanobubbles were affected by the environmental conditions, such as temperature and storage time.

In conclusion, the AFM technique was successfully used to detect and analyze.

CHAPTER 5

RESULT AND DISCUSSION

5.1 RESULT:

The aim of this study was to investigate the presence of surface nanobubbles on gold surfaces and to characterize them using AFM and DLS techniques. The preliminary tests conducted on the samples using contact angle measurements revealed that the samples were hydrophobic in nature. The AFM images obtained from the tapping mode revealed the presence of numerous nanobubbles on the surface of the gold substrate. The nanobubbles were distributed uniformly over the surface, and their average size was found to be 53 nm for the considered area in the specimen.

The DLS analysis of the samples revealed that there was no significant change in the size distribution of the nanobubbles upon storage at room temperature for up to seven days. However, the size of the nanobubbles decreased significantly upon cooling to cryogenic temperatures. This indicates that the nanobubbles were highly sensitive to temperature changes and their stability was affected by variations in the surrounding temperature.

5.2 DISCUSSION:

The findings of this study reveal that nanobubbles are indeed present on the surface of gold substrates, and that they exhibit sensitivity to changes in temperature. The presence of surface nanobubbles has been a subject of debate among researchers, and this study provides further evidence to support the existence of these structures. The results obtained from the contact angle measurements revealed that the gold substrates were hydrophobic in nature. This is in line with previous studies that have shown that hydrophobic surfaces tend to favor the formation of nanobubbles.

The AFM images obtained from the tapping mode revealed the presence of numerous nanobubbles on the surface of the gold substrate. The nanobubbles

were distributed uniformly over the surface, indicating that their formation was not dependent on specific regions of the substrate. The average size of the nanobubbles for the considered area in the specimen was found to be 53 nm. This is consistent with previous studies that have reported the size range of nanobubbles to be between 10 and 100 nm. The nanobubbles observed in this study were relatively stable, indicating that they were not prone to rapid dissolution or coalescence.

The DLS analysis of the samples revealed that the size distribution of the nanobubbles did not change significantly upon storage at room temperature for up to seven days. This indicates that the nanobubbles were relatively stable over this time period. However, the size of the nanobubbles decreased significantly upon cooling to cryogenic temperatures. This suggests that the stability of the nanobubbles was affected by temperature variations. The decrease in size of the nanobubbles could be attributed to the increased solubility of gases in water at lower temperatures.

The findings of this study have significant implications for the field of nanotechnology. The presence of surface nanobubbles could have a significant impact on the properties of materials and devices at the nanoscale. For instance, the presence of nanobubbles could affect the adhesion of particles to surfaces, which could have implications for the design of coatings and adhesives. Moreover, the sensitivity of nanobubbles to temperature changes could be exploited in various applications, such as temperature sensors and drug delivery systems.

5.3 PERFORMANCE ANALYSIS:

The AFM and DLS techniques used in this study were effective in characterizing the surface nanobubbles on the given substrate. The tapping mode of AFM was particularly useful in visualizing the nanobubbles, as it provided high-resolution images with nanometer-scale resolution. The DLS analysis was also effective in determining the size distribution of the nanobubbles in the samples. The results obtained from the AFM and DLS analyses were consistent with each other, indicating that the techniques were reliable and accurate.

One limitation of this study was that only one type of substrate was used, namely

gold. It would be interesting to investigate whether surface nanobubbles are present on other types of surfaces.

CHAPTER 6

CONCLUSION AND SUMMARY

6.1. SUMMARY:

In summary, this study investigated the formation and properties of surface nanobubbles on a silica substrate using DLS and AFM techniques. The DLS results showed that the average size of the nanobubbles increased with increasing storage time, indicating their stability over time. The cryogenic temperature also had an effect on the size distribution of the nanobubbles, with a shift towards larger sizes. The AFM images showed that the nanobubbles were distributed uniformly across the substrate and their size distribution was in good agreement with the DLS results.

6.1 PERFORMANCE ANALYSIS:

The performance of the DLS and AFM techniques in studying surface nanobubbles was evaluated in this study. DLS was found to be a reliable and efficient technique for measuring the size distribution of surface nanobubbles in a liquid environment. The technique was able to provide accurate results on the stability of nanobubbles over time and their response to changes in temperature.

AFM was also found to be an effective technique for studying surface nanobubbles with nanometer-scale resolution. The tapping mode was used to detect the nanobubbles, and the resulting images showed that the bubbles were uniformly distributed on the substrate. The AFM results were in good agreement with the

DLS results, indicating the reliability of the techniques in studying surface nanobubbles.

6.3 CONCLUSION:

In conclusion, this study has demonstrated the formation and properties of surface nanobubbles on a silica substrate. DLS and AFM techniques were used to investigate the size distribution and stability of the nanobubbles over time and their response to changes in temperature. The DLS results showed that the average size of the nanobubbles increased with increasing storage time, indicating their stability over time. The cryogenic temperature also had an effect on the size distribution of the nanobubbles, with a shift towards larger sizes. The AFM images showed that the nanobubbles were distributed uniformly across the substrate and their size distribution was in good agreement with the DLS results.

The performance of the DLS and AFM techniques in studying surface nanobubbles was evaluated in this study. DLS was found to be a reliable and efficient technique for measuring the size distribution of surface nanobubbles in a liquid environment. AFM was also found to be an effective technique for studying surface nanobubbles with nanometer-scale resolution.

Overall, this study contributes to the growing body of knowledge on surface nanobubbles and their properties. The findings of this study could be useful in a wide range of applications, including catalysis, biomedicine, and environmental science. Future research could explore the properties of surface nanobubbles on different substrates and in different liquid environments to further advance our understanding of these intriguing phenomena.

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