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The Interplay between Water Purity and Oxygen Content in Micro bubble Surface Cleaning Effectiveness

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Introduction

Surface cleaning plays a critical role in a wide range of industries, from food processing to semiconductor manufacturing, where maintaining high hygiene standards and preventing contamination are paramount. Recent advancements in cleaning technologies have introduced the use of micro bubbles, a method that offers several advantages over traditional cleaning approaches. Micro bubble cleaning utilizes the power of tiny bubbles, typically smaller than 100 micrometers in diameter, to generate physical forces capable of dislodging contaminants from surfaces. This method has garnered significant interest for its environmentally friendly nature and its ability to achieve high-efficiency cleaning without the need for harsh chemicals.

However, the effectiveness of micro bubble-assisted cleaning is influenced by various factors, including the purity of the water used and the oxygen content within the gas phase of the micro bubbles. Water purity and oxygen concentration have profound effects on the generation and stability of micro bubbles, which in turn impact their cleaning efficacy. This article delves into the complex interplay between water purity and oxygen content and their combined effect on the performance of micro bubble-based surface cleaning systems.

Description

Micro bubbles are created by introducing gas (typically air or oxygen) into water under controlled conditions. The gas is then injected into the liquid in such a way that it forms bubbles with diameters typically ranging from 10 to 100 micrometers. These micro bubbles, while small in size, have a large surface area and are capable of generating a significant amount of physical and chemical energy when they collapse or burst upon contact with surfaces. This unique ability to generate high shear forces, along with their potential for generating Reactive Oxygen Species (ROS) when oxygen is present, makes micro bubbles highly effective for cleaning purposes. The mechanism of micro bubble cleaning relies on several factors, including cavitation, bubble bursting and the release of mechanical energy. When micro bubbles collapse near a surface, they create localized high-pressure waves that can remove particles, microorganisms and other contaminants. Additionally, when oxygen is present, microbubbles can promote oxidative reactions that further assist in breaking down organic contaminants [1].

Water impurities such as dissolved minerals, organic matter and microorganisms can hinder the formation of stable microbubbles. In pure, deionized water, the formation of micro bubbles tends to be more efficient, as the absence of contaminants allows for a smoother generation process. However, in the presence of impurities, the dynamics of bubble formation can be altered. For example, the presence of dissolved salts and minerals can lead to the formation of larger, less stable bubbles that are less effective at generating the necessary forces for surface cleaning. This can result in reduced cleaning efficiency, as the bubbles are less likely to dislodge contaminants effectively. In addition, organic compounds in the water can form films around the bubbles, reducing their surface area and preventing the bubbles from collapsing with sufficient force to remove contaminants. Therefore, using high-purity water in micro bubble cleaning systems ensures that the bubbles are smaller, more stable and capable of generating the desired cleaning forces [2].

Water hardness, which is determined by the concentration of calcium and magnesium ions in the water, can significantly affect the performance of micro bubbles. Hard water can lead to the formation of scale deposits on surfaces, which can interfere with the cleaning process. Additionally, the presence of calcium and magnesium ions can alter the behavior of micro bubbles, leading to the formation of larger bubbles that are less effective at cleaning. By using soft or deionized water, the cleaning efficiency of micro bubbles can be optimized, as it reduces the likelihood of scale formation and allows for better bubble formation and stability. The presence of oxygen in the gas phase of micro bubbles allows for the generation of reactive oxygen species such as hydroxyl radicals (OH) and superoxide anions ($O_2^{\bullet -}$). These highly reactive molecules can break down organic pollutants, bacteria and other contaminants on the surface. The generation of ROS is particularly important when cleaning organic materials such as oils, fats and proteins, as these substances are more susceptible to oxidative degradation. When oxygen is injected into the gas phase of microbubbles, it significantly enhances the cleaning efficiency by promoting oxidative reactions. For example, in food processing applications, where biofilms of bacteria or organic matter may be present on surfaces, oxygen-rich microbubbles can accelerate the breakdown of these organic contaminants, resulting in more effective cleaning. Furthermore, the increased oxygen content can enhance the stability of the microbubbles, as oxygen is a less volatile gas compared to other gases like nitrogen, which can lead to quicker bubble collapse [3].

In addition to promoting oxidative reactions, oxygen content in the gas phase of microbubbles can influence the cavitation process. Cavitation refers to the formation and collapse of microbubbles, generating shock waves that contribute to cleaning. The presence of oxygen in the gas phase can increase the intensity of cavitation by promoting bubble collapse with greater energy release. This results in enhanced cleaning force at the surface, which is crucial for removing stubborn or embedded contaminants. Thus, by controlling the oxygen content in the gas phase, microbubble cleaning systems can be optimized for specific cleaning tasks. The interplay between water purity and oxygen content is key to maximizing the effectiveness of microbubble-based surface cleaning. Both factors contribute to the stability, formation and reactivity of microbubbles and their combined influence determines the efficiency of the cleaning process. For optimal performance, microbubbles should be generated in high-purity water with a controlled oxygen concentration. Using pure, deionized water ensures that the microbubbles are smaller and more stable, which allows for better penetration and cleaning of surfaces. On the other hand, introducing oxygen into the gas phase promotes oxidative reactions that enhance the cleaning of organic contaminants. Moreover, the use of oxygen-rich microbubbles in high-purity water enables the system to generate more stable bubbles that release greater energy upon collapse, creating higher shear forces that can effectively remove contaminants from surfaces. In contrast, the use of impure water with low oxygen content can result in larger, less stable bubbles that fail to deliver the same cleaning effectiveness [4,5].

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Conclusion

The effectiveness of microbubble-based surface cleaning systems is significantly influenced by both water purity and the oxygen content in the gas phase. High-purity water ensures that microbubbles are stable and small enough to effectively remove contaminants, while oxygen content promotes oxidative reactions that enhance cleaning efficiency. The interplay between these two factors is essential for optimizing the performance of microbubble cleaning systems in a wide range of industries, from food processing to semiconductor manufacturing. As research into microbubble technology continues to advance, a better understanding of how water purity and oxygen content influence cleaning effectiveness will be crucial for developing more efficient and sustainable cleaning solutions.

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Conflict of Interest

There is no conflict of interest by author.

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