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授 与 学 位	博士（工学）
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学位論文題目	Development of Air Bubble-Mediated Separation and Purification Methods (気泡を用いる分離・精製技術の開発)
論文審査委員	主査　教　授　齋　藤　　徹 教　授　小　西　正　朗 准教授　霜　鳥　慈　岳 教　授　南　　尚　嗣 准教授　邱　　泰　瑛

学位論文内容の要旨

It was found that the air-water interface (air-bubbles) could be used as a separation medium for the purification of dyes and pharmaceuticals. Air bubbles are a harmless, waste-free medium with a low environmental impact. This study suggests that the air-water interface has solvent properties comparable to those of ethyl acetate and is effective in the purification of the basic dye Rhodamine B and the anti-malarial drug Chloroquine, providing the basis for a possible new method of substance separation and purification.

In Chapter 2, the hydrophobic properties of bubbles as separation media were clarified by analysis using fluorescent probes and ultrafine bubbles (UFB), which are stable in water. Measurements using the fluorescent molecule 1,2'-dinaphthylamine, which is used to evaluate hydrophobic field, observed that water containing UFB is a much more hydrophobic solvent than water.Through this comprehensive research approach, I aimed to provide valuable insights into the preferences and expectations of Chinese tourists when selecting and experiencing tourist sites in Hokkaido. The results of this study can serve as a basis for industry stakeholders to tailor their offerings and marketing strategies to better meet the interests and needs of Chinese tourists, ultimately strengthening the tourism industry in Hokkaido and beyond.The hydrophobicity of the bubbles was similar to that of ethyl acetate and diethyl ether, indicating
the characteristics of bubbles as separation media.

Chapter 3 shows a rapid purification method for chloroquine based on flotation. Chloroquine, an antimalarial drug, is synthesized in about 80% yield by 4-amino-1diethylaminopentane and 4,7-dichloroquinoline. It has been purified by solvent extraction and then recrystallization. The method designed utilizes the differences in hydrophobicity and ionicity between the source material and the product, achieving a rapid separation in less than 10 minutes. The purity of the product was more than 99% by HPLC analysis. The use of bubbles as a separation medium has been shown to provide low environmental impact pharmaceuticals purification.

Chapter 4 was a fundamental study for industrial continuous treatment combined with microfiltration (MF). MF membranes have the advantage of good permeability and resistance to

fouling, but their large pore size prevents them from blocking low molecular compounds such as dyes. We found that a specific dye can be blocked by passing a solution containing bubbles larger than the membrane pore size through an MF membrane, taking advantage of the properties of bubbles.

Air-bubbles as a separation medium were found to have solvent properties similar to ethyl acetate and could rapidly adsorb and separate compounds with strong hydrophobic properties. it is even possible to prevent the permeation of compounds into the microfiltration membrane by means of adsorption of molecules on the bubbles. It is hoped that this research will provide the beginnings of a new low environmental impact separation method that could contribute to a sustainable society.

審査結果の要旨

気泡を用いる分離技術は簡便性・迅速性に優れており、古くから界面活性剤やキレート化剤を系に添加する泡沫分離やイオンフローテーション等が盛んに研究されてきた。一方、これまでの研究では、気泡は界面活性剤やキレート化剤と結合した分離対象物質の運搬体として見做され、気泡の持つ分離媒体としての可能性を検討した研究例は限られていた。学位申請者 児玉 康輝 氏は、気液界面への薬物や色素の吸着に着目し、気泡表面（気液界面）を薬物捕捉場として利用する分離技術の可能性を検討した。気泡の浮上に基づくフローテーションにおいて、薬物や色素の吸着に十分な気液界面積と溶液の混合・拡散に対抗する上昇速度を有する気泡のサイズを両立させる条件を見出し、気泡のみを用いる新規な分離技術を開拓した。蛍光色素ローダミン B と抗マラリア薬クロロキンの原料や中間体を含む粗製品の精製に本法を適用し、５分×３回の分離操作により、市販標準品と同等の高純度品を得ることができた。さらに、将来的な実用化装置設計の基礎検討の一環として、膜分離技術との融合を検討した。分子やイオンは通過するが、気泡は通過しない濾過膜を用い、気泡への吸着力が強いローダミン B を選択的に阻止できる可能性を見出した。以上、従来の研究では顧みられてこなかった気液界面の性質をそのまま利用した新規分離技術を創案し、色素や薬物など気液界面への吸着性を有する化合物の分離精製への適用可能性を明らかにした。

よって、本研究は分離科学の発展に貢献するところ大なるものがあり、審査委員全員が、申請者は北見工業大学博士（工学）の学位を授与される資格があるものと認めた。