様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費
KAKENHI

科学研究費助成事業　　研究成果報告書

令和　３ 年 １２ 月　 ９ 日現在

機関番号：１４３０１
研究種目：若手研究
研究期間：2019～2020
課題番号：１９Ｋ１５３３７

研究課題名（和文）Finebubble generation in a continuous system with microchannels

研究課題名（英文）Finebubble generation in a continuous system with microchannels

研究代表者
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交付決定額（研究期間全体）：（直接経費）　　2,600,000円

研究成果の概要（和文）：この研究期間中に、いくつかのファインバブル（FB）ノズルのプロトタイプが開発し、3Dプリントされた。開発したノズルの性能は、いくつかの気液比の下でのガス吸収性能によって評価された。最良の動作条件では、バッチ式動作で20分以内に水の酸素濃度が過飽和状態になった。そして、液中に含まれるFBをNTA法を用いて測定を行った。その結果、100nm～300nmの大きさのFBが1mLあたり平均3.5億個含まれていることがわかった。
細い流路でのスラグ流を用いた場合、液体スラグの内部循環によりFBが変形し、その数や大きさが変化することがわかった。1mLあたり3億個以上のFBが連続的に発生した。

研究成果の学術的意義や社会的意義
一般的に、FBはバッチ式に生成され、液体の高流量に生成される。本研究では、FBノズルを開発し、小流量の液体に対応し、連続的にFBを発生させることができた。この研究は、マイクロ化学プロセスへの応用が期待できる。

研究成果の概要（英文）：During this research period, several prototypes of fine bubbles nozzles were 3D printed. The performance of the nozzles was evaluated through their gas absorption performance under several gas-to-liquid ratios. Under the best operating conditions, water was oversaturated with oxygen within 20 minutes of batch-wise operation. Then, the fine bubbles contained in the liquid were measured by using the Nano Tracking Analysis (NTA) method. The results showed an average of 350 million bubbles per mL with a size between 100 nm and 300 nm.
The use of slug flow in small channels showed that the fine bubbles suffer deformations due to the internal mixing in the liquid slug. Such flow deformation cause changes in the number and size of fine bubbles. Finally, the fine bubbles were generated continuously using two flow patterns: continuous flow and cyclic flow. In both cases, over 300 million bubbles per mL were constantly generated.

研究分野：プロセスシステム工学

キーワード：fine bubbles　slug flow　gas absorption　small channels

1．研究開始当初の背景

Fine bubbles (gas bubbles of less than 0.1 mm in diameter) have the following important features: ① an increase in the surface area per volume of gas; ② an increase in the residence time in the liquid phase due to the decrease buoyancy; and ③ an increase in bubble internal pressure due to surface tension. These features imply: ① high mass transfer and heat transfer, ② the gas can be immersed in the liquid for a long time, and ③ fast size reduction of gas bubbles.

Microchannels have the following important features: ① a decrease in the Reynolds number (Re), resulting in laminar flow more easily; ② an increase in the surface area per volume of fluid; and ③ a decrease of the fluid volume in the containing channel. These features imply: ① easy control of the residence time in mixing and reaction processes by keeping the laminar flow, ② high mass transfer and heat transfer, and ③ the reduction of equipment size and space, which can help to make smaller equipment and processes.

Few studies try to understand the motion, dispersion, and gas-liquid mass transfer of FB in batch-wise apparatuses[1]. Nevertheless, the motion, dispersion, and gas-liquid mass transfer of FB in MC remain unclear. Batch processes have the disadvantages of batch-to-batch variation in the products, small throughput, high initial cost, and unproductive time spent in preparation of a new batch.

To overcome these issues, new processes that use FB must be done in a continuous way. In this sense, MC can help to realize continuous process operation.

2．研究の目的

The first objective is to match the scale of FB and MC because current processes using FB handle a big batch size (few liters to a few hundred liters) while processes using MC handle small throughput (few ml/min).

The second objective is to change from batch-wise FB systems to continuous FB systems because typical systems are done batch-wise [1]. The originality of this research is to develop a FB system that can continuously generate FB by recirculating the liquid partially with FB. It means part of the liquid with FB will continuously go through microchannels.

3．研究の方法

The performance of FB generation devices will be evaluated by measuring the dissolved oxygen (DO) in water and by measuring the particle size distribution of FB. These results can be used to derive the mass transfer coefficient value. To develop FB generation devices, a 3D printer (Yokoito Co. Forms 2) and 3D printing software (Autodesk Fusion 360) were used.

The motion and dispersion mechanism of FB in MC will become clear by doing the proposed experiments. The results from this research will help to increase the applications of FB in continuous processes as well as to the applications of FB for small flow throughput. Also, the mass transfer enhancement in processes contacting gas and liquid can open the possibility to increase applications of processes limited by mass transfer.

The FB size distribution and the number were calculated by using the Nano Tracking Analysis (NTA) method. Also, the continuous generation of FB was done under two flow patterns: ① continuous generation of FB ② cyclic generation of FB.

4．研究成果

Several FB generation devices were designed in the software Fusion 360 and printed in the 3D printer Forms 2 (Yokoito Corp.). Several obstacles were included in the devices to enhance contact between gas and liquid phases. Figure 1 shows the types of obstacles in the FB generation devices. All the obstacles generated FB and surpass the saturation concentration of dissolved oxygen at high gas flows as shown in Figure 2.

Figure 1. Gas absorption performance of FB generation devices

Figure 2 shows a comparison of several FB devices at two different values of gas flow. The best performance was obtained when a screw-type static mixer was used [2, 3]. At 50 mL/min gas flow rate, the saturation concentration of oxygen (dotted line Fig. 1) was surpassed. It means that the presence of oxygen in water is as dissolved oxygen and undissolved oxygen in form or air fine bubbles.

Figure 3 shows the size distribution and amount of FB for some FB generation devices. The NTA method was used to do the measurements. It was observed that the FB size distribution is within 100 and 300 nm as reported by commercial devices. The FB amount was between 159 million bubbles/mL and 1.23 billion bubbles/mL for the screw-like A device. This latter result outperforms current commercial devices.

Figure 4 shows the size distribution and amount of FB for two flow patterns. In Pattern 1, FB are generated continuously when fresh distilled water enters the FB generation systems, and water with FB exists from the system. In Pattern 2, FB are generated in a cyclic way when fresh distilled water enters the FB generation for t_1 minutes. Then, water with FB exists from the system for t_2 minutes. The process is repeated cyclically. In both flow patterns, around 300 million bubbles/mL with size within 100 to 300 nm were generated. These results are similar to those reported by commercial devices. Therefore, FB can be generated continuously in small channels.

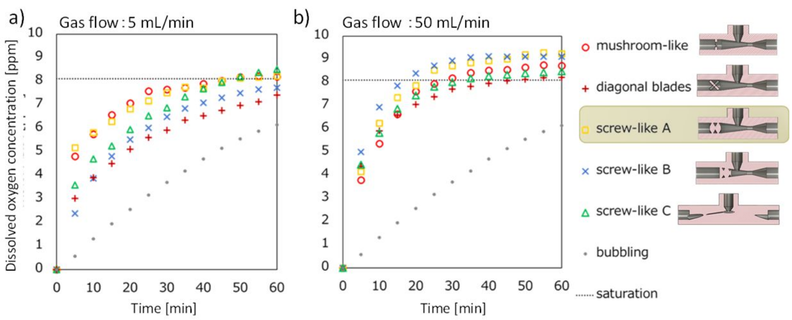

Figure 2. Gas absorption performance of FB generation devices

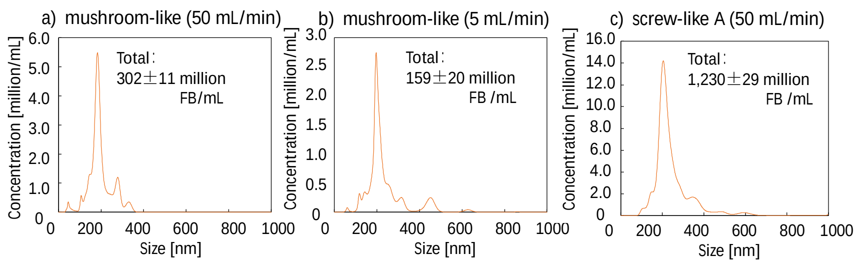

Figure 3. FB amount and size distribution for some generation devices

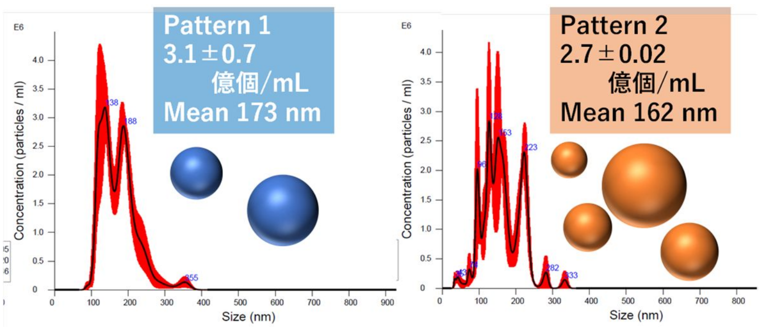

Figure 4. Flow patterns for continuous generation of FB: continuous (left), and cyclic (right)

＜引用文献＞

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2. **池本 陸，ファインバブル生成装置の開発と酸素吸収による性能評価，文京都大学工学研究科化学工学専攻、**2021
3. Riku Ikemoto, J.R. Alcantara-Avila, Evaluation and comparison of oxygen absorption performance of several fine bubble generators, International Congress of Chemical and Process Engineering (CHISA 2021 Virtually), Online, March 2021.

5．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計2件（うち招待講演　0件／うち国際学会　1件）

1．発表者名 池本 陸、Alcantara Avila J. Rafael
2．発表標題 ファインバブル生成装置の開発と酸素吸収効率による性能評価
3．学会等名 化学工学第８５年会
4．発表年 2020年

1．発表者名 Riku Ikemoto, J.R. Alcantara-Avila
2．発表標題 Evaluation and comparison of oxygen absorption performance of several fine bubble generators
3．学会等名 International Congress of Chemical and Process Engineering（国際学会）
4．発表年 2021年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関