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DESIGN AND PERFORMANCE OF HONEYCOMB STRUCTURE FOR NANOBUBBLES GENERATING APPARATUS

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Abstract: In recent years, nanobubble technology has drawn great attention due to their wide applications in many fields of science and technology, such as seafood long term storage by using nitrogen nanobubble water circulation to slow the progressions of oxidation and spoilage. From previous study, a kind of honeycomb structure for high efficiency nanobubble generation has been investigated. In addition, the small-scale honeycomb structure is designed for the broader applications. Comparing with stainless steel, acrylic resin and titanium have good corrosion resisting property in various liquids including the sea water. Therefore, acrylic resin and titanium are considered in this study. In this paper, the honeycomb structure is optimized and improved. The strength of the honeycomb structure is also analyzed by FEM. The relationship between nanobubble generation efficiency and structure type is discussed.

Keywords: honeycomb, nanobubble, FEM

1 INTRODUCTION

In recent years, nanobubble technology has drawn great attention due to their wide applications in many fields of science and technology, such as water treatment, biomedical engineering, and nanomaterials. Nanobubble technology is also used for seafood long term storage. The nitrogen nanobubble water circulation can be used to reduce the oxygen in water and slow the progressions of oxidation and spoilage[1].

From previous study, a kind of honeycomb structure for high efficiency nanobubble generation has been investigated[2][3]. In addition, the small-scale honeycomb structure is designed for the broader applications. Comparing with stainless steel, acrylic resin and titanium have good corrosion resisting property in various liquids including the sea water. Therefore, acrylic resin and titanium are considered in this study.

In this paper, the honeycomb structure for nanobubble generation is optimized and improved. The strength of the honeycomb structure is also analyzed by FEM. The relationship between nanobubble generation efficiency and structure type is discussed.

2 NANOBUBBLE GENERATION EXPERIMENT WITH TITANIUM HONEYCOMB STRUCTURE

The oxygen dissolved in water is one of the main causes of the spoilage. Using nitrogen nanobubble water is an effective way to reduce the dissolved oxygen (DO) to prevent spoilage and keep the fish fresh for a long time. Fig. 1 shows the experimental device for nitrogen nanobubbles generating and Table 1 shows the details of the experimental device. The water and the nitrogen gas are pumped into the bubble generator together as shown in Fig. 1(a). There are 12 or 15 honeycomb structure units placed parallel inside the bubble generator as shown in Fig. 1(b).

Table 1 Details of the experimental device

Pump Output Flow rate	Submersible pump(50TM21.5) 1.5kW, 60Hz 200L/min
Container	W1580mm×D1100mm×H600mm
Water and amount	Tap water, 1000kg
Gas Flow rate Pressure	Nitrogen 5.0ℓ/min 0.2MPa

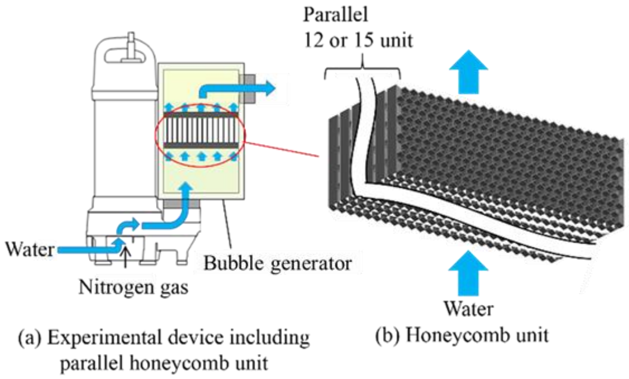


Fig. 1 Nitrogen nanobubbles generating device

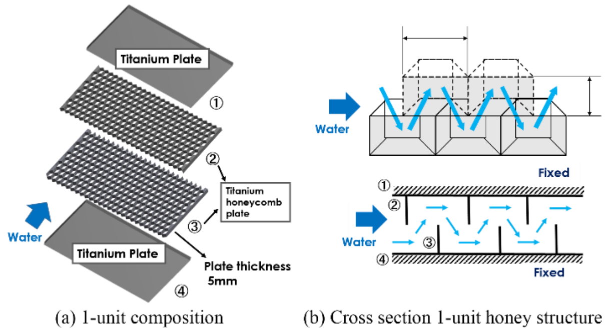


Fig. 2 Honeycomb structure model

Fig. 2 shows the model of the honeycomb structure. The turbulence will occur when the gas-liquid mixture flows through the complex flow channels constituted by the overlapped honeycomb plates. As the gas-liquid mixture flows from a wide flow path to a narrow flow path, the shear field is formed due to the pressure change, which makes the nitrogen bubbles finer[1]. The experimental condition is shown in Table 2.

Table 2 Experimental condition

	Number of units	Clearance (mm)	Pressure (MPa)	Flow rate (L/min)	Frequency (Hz)
①	15	0	0.20	550	60
②	12	2	0.06	———	60
③	12	0	0.16	650	60
④	12	0	0.01	300	30

The dissolved oxygen (DO) and nanobubbles density will be investigated in the experiment. Furthermore, the honeycomb structure unit with 2mm clearance between two honeycomb plates, which is shown in Fig. 3, will be considered for comparison. The experimental results of DO are shown in Fig. 3. The experimental device has 12 honeycomb structure units inside. At the beginning, the DO of 0mm clearance case is 9.2mg/L and the DO of 2mm clearance case is 8.7mg/L. 15 minutes later the DO of 0mm clearance case becomes lower than that of 2mm clearance case. At the end of 30 minutes, the DO of 0mm clearance case is 1.8mg/L and the DO of 2mm clearance case is 2.4mg/L. Table 3 shows the nanobubbles density. The average shear force decline caused by clearance leads to the lower nanobubbles density. The DO decreases slowly with low nanobubbles density.

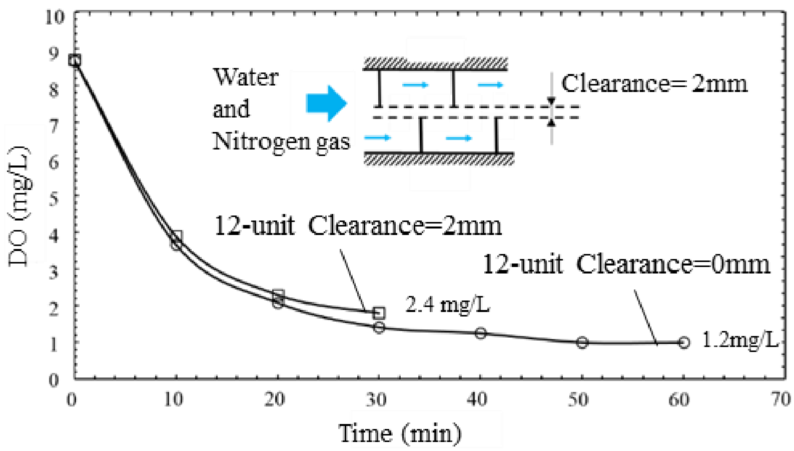


Fig. 3 Change of DO with the time

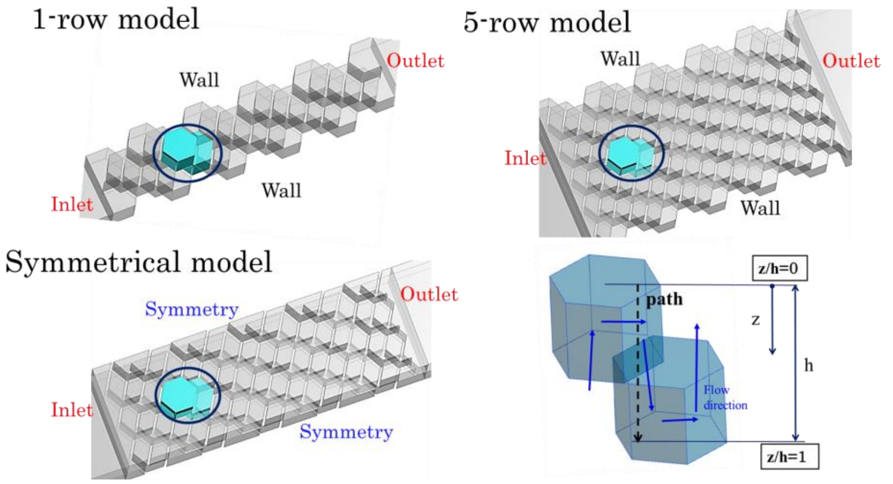
Table 3 Change of nanobubbles density with the time

Time (min)	Nanobubbles density (/mL)		
	Clearance=0mm		Clearance=2mm
	15-unit	12-unit	12-unit
0	0.43×10^8	0.19×10^8	0.10×10^8
30	1.78	1.74	0.56
60	2.66	2.41	——

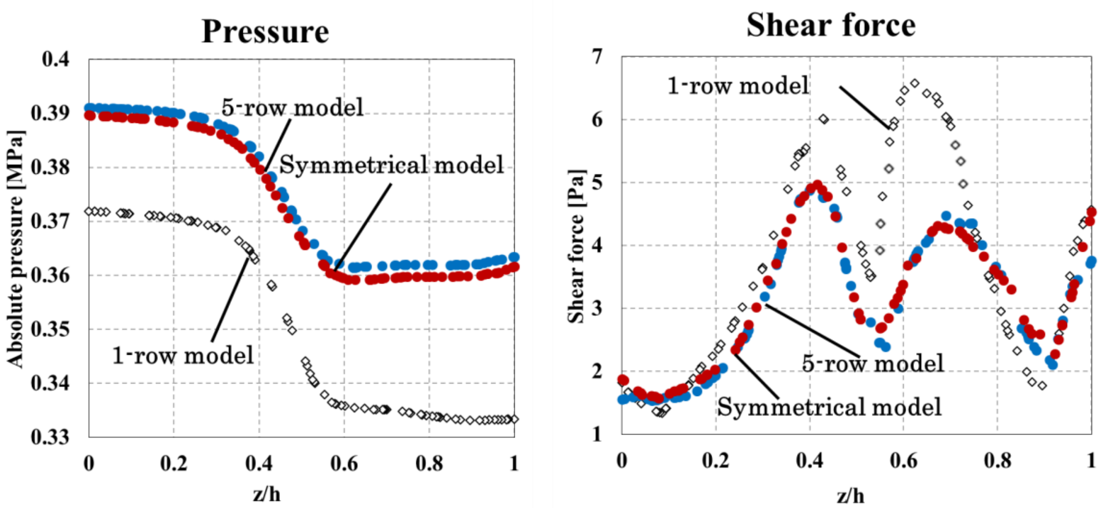
3 FEM ANALYSIS OF THE FLUID AND THE HONEYCOMB STRUCTURE STRENGTH

3.1 FEM ANALYSIS OF THE FLUID

In order to simplify, only part of the honeycomb structure will be modeled for FEM analysis. Fig. 4(a) shows three types of fluid model with different size. It should be noted that the symmetry boundary conditions are applied in the symmetrical model to simulate the situation of more rows. In each case, the inlet pressure is 0.35MPa. The pressure and shear force distributions in the same position of each model are investigated and the results are shown in Fig. 4(b). The results of 1-row model are quite different with the results of two other models. That is because the investigated position in 1-row model is too close to the walls and the walls have effects on the fluid. The 1-row model cannot simulate the fluid in the honeycomb structure accurately. In order to avoid the influence of the walls, at least 5 rows should be modeled for analysis. From Fig. 5, it can be found that the average shear force of the honeycomb structure with clearance is lower.



(a) Three types of fluid model



(b) Pressure and shear force distributions of three models

Fig. 4 Fluid models

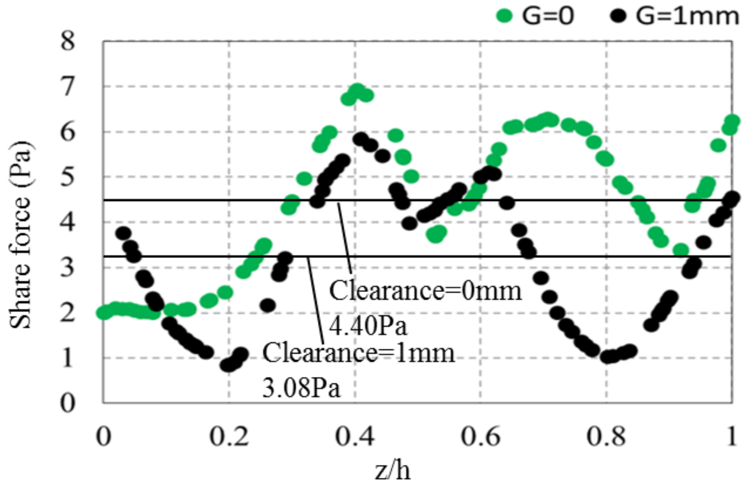
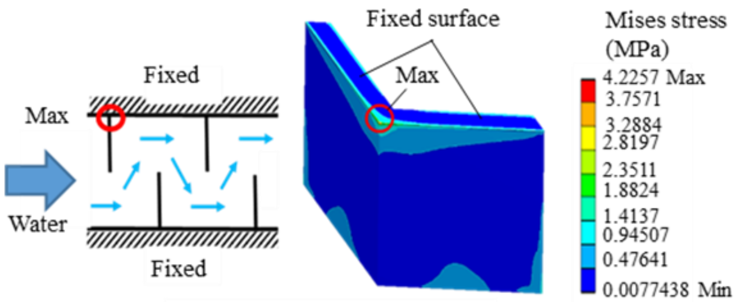


Fig. 5 Shear force when clearance = 1mm

3.2 FEM ANALYSIS OF THE HONEYCOMB STRUCTURE STRENGTH

The strength of the titanium and acrylic honeycomb structures will be analyzed in this section. The honeycomb wall thickness is 0.5mm for titanium structure, and 0.5mm and 2mm for acrylic structure. The inlet pressure is 0.35MPa. Fig. 6 shows the FEM results of titanium honeycomb structure. The results of the titanium structure and acrylic structure are charted in Table 4. In each case, the maximum Mises stress is far less than the yield stress and the maximum deformation is quite small, the honeycomb structure is safe.



$\sigma_{eq}^{Max} = 3.18$ MPa (Mises stress)

$\sigma_{i}^{Max} = 4.15$ MPa (Max principal stress)

Fig. 6 FEM results of titanium honeycomb structure

Table 4 FEM results of honeycomb structures

Material (Wall thickness)	Maximum Mises stress (MPa)	Yield stress (MPa)	Maximum principal stress (MPa)	Maximum deformation (mm)
Titanium (0.5mm)	4.23	700	5.63	6.9×10^{-5}
Acrylic (0.5mm)	4.04	75	5.66	2.0×10^{-3}
Acrylic (2mm)	1.53	75	1.93	6.0×10^{-4}

4 CONCLUSIONS

The device with honeycomb structure can make nitrogen nanobubbles to reduce the DO in water efficiently. The clearance between two honeycomb plates in each honeycomb structure unit will weaken the shear field of the fluid, which leads to weak ability of nanobubbles producing for DO decreasing.

The fluid model is investigated. The walls have effects on the fluid, so that 1-row model cannot simulate the fluid in the honeycomb structure accurately. In order to avoid the influence of the walls, at least 5 rows should be modeled for analysis. Similar to the experimental results, from FEM analysis it can be found that the clearance causes lower shear force.

The strength of the honeycomb structure is also analyzed by FEM. In each case, the maximum Mises stress is far less than the yield stress and the maximum deformation is quite small, the honeycomb structure is safe.

The honeycomb structure has the advantages of light weight, small size and high efficiency. This paper provides some references for the further research on nanobubble technology.

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