A NOVEL CHAOTIC MICROMIXER:
BARRIER EMBEDDED KENICS MICROMIXER

Dong Sung Kim, In Hwan Lee, Tai Hun Kwon* and Dong-Woo Cho
Department of Mechanical Engineering, Pohang University of Science and Technology (POSTECH), San 31 Hyoja-dong Nam-gu, Pohang, 790-784, Korea
Telephone: 82-54-279-2175 Fax: 82-54-279-5899 E-mail: thkwon@postech.ac.kr

Abstract
In this paper, we present a new chaotic micromixer named Barrier Embedded Kenics Micromixer (BEKM) having a fully 3-dimensional geometry that was realized by microstereolithography. BEKM is a modified Kenics micromixer by introducing barriers on the cylinder wall periodically to enhance the mixing via the chaotic mechanism of stretching and fording in the helical flow induced by twisted helical elements. Our experimental results indicate clearly the improvement of the chaotic mixing efficiency of BEKM.

Keywords: Chaotic Mixing, Modified Kenics Micromixer, Barrier, Microfluidics

1. Introduction
Mixing plays a very important role in microfluidic systems such as BioMEMS and µTAS [1-2]. Because of low Reynolds number (Re) of the microchannel flow, it is impossible to achieve turbulent mixing of two fluids. Chaotic mixing in the Stokes flow regime could remarkably enhance the mixing efficiency. Kim et al. [1] obtained the chaotic mixing by introducing alternating velocity fields via periodic barriers in a rectangular microchannel. Bertsch et al. [2] fabricated micromixers miniaturizing conventional static mixers: Kenics™ and SMX™ mixers. The mixing mechanism of the two mixers is the combination of splitting and reorientation, causing chaotic mixing. They concluded that the SMX micromixer was a better mixer than Kenics mixer in terms of a mixing efficiency, but at the cost of higher pressure loss. Moreover, the intricate microstructures inside the SMX micromixer could be damaged, which might be the critical drawback. In this regard, it is of interest to improve the Kenics micromixer with respect to the mixing efficiency while maintaining the low pressure loss. This is exactly what is achieved by the present BEKM. BEKM becomes a very efficient chaotic micromixer by combining the “splitting/reorientation” of the conventional Kenics mixer with the “stretching/folding” by means of periodically located barriers with relatively low pressure loss.

2. Design Concepts and Experimental
Figure 1 shows a Kenics micromixer fabricated by microstereolithography [3] in this study. Two inlets of 1000 μm×1000 μm square cross-section were placed at one end of the Kenics cells. At the outlet part, outer diameter of 2000 μm was formed for the easy connection to the drain tube. The cell parts were composed of six 180°-twisted helical elements, as separation walls, in a circular pipe. Counterclockwise- and clockwise-rotated helical elements were alternately arranged, causing splitting/reorientation of fluid flow. Each helical element is 1640 μm long and 100 μm thick.

A BEKM was newly designed and fabricated by microstereolithography as shown in Figure 2. Four barriers were introduced at the pipe wall in each Kenics cell. Each barrier was 100 μm thick, 150 μm high and 413 μm long. The overall dimensions and shape were the same as the Kenics micromixer. The helical element causes the relative transversal flow, which is schematically indicated in Figure 3(a), consequently generating the helical flow together with the axial flow. Therefore, in the region with no barrier, the cross-sectional flow contains one elliptic point. In contrast, in the region of barrier, the cross-sectional flow field can be characterized by two co-rotating flows, which have one hyperbolic point and two elliptic points as indicated in Figure 3(b). Periodically alternating flow fields of Figure 3(a) and (b) result in a strong chaotic mechanism of stretching/folding, thereby enhancing the mixing performance of BEKM. It may be further noted that the level of mixing efficiency could be achieved with a relatively small increase of pressure loss, as was proved by our group [1,4].

Two fluid flows containing different solutes (NaOH and phenolphthalein which changes its color from colorless to red if pH becomes greater than eight) were driven by a syringe pump at the constant flow rate (Re = 10).

Figure 1. Kenics micromixer developed in this study: (a) schematic view with dimensions, (b) real overview and (c) SEM picture of cross-sectional shape of one cell.
3. Results and Discussion

Figure 4 shows mixing experimental results of both Kenics micromixer and BEKM, indicating that mixing in BEKM is qualitatively better achieved. To quantify the mixing efficiency, we measured the intensity of red color at every pixel in several areas along the downstream direction. The change of normalized average intensity, \( I = \frac{\sum_{n=1}^{N} I_n}{N} \) (where \( I_n \) and \( N \) are measured normalized intensity at \( n \)-th pixel and total number of pixels in each area, respectively) is plotted in Figure 5, which clearly shows the improved mixing performance of BEKM.

4. Conclusion

We proposed a new chaotic micromixer, BEKM. Periodical change of two velocity fields, as depicted in Figure 3, causes the efficient chaotic mechanism of stretching and folding, inducing exponential interfacial area growth, and consequently resulting in more efficient chaotic mixing of the BEKM than that of the Kenics micromixer.
Figure 4. Mixing experimental results of (a) Kenics micromixer and (b) BEKM.

Figure 5. Normalized average intensity change of red color along the downstream direction of Kenics micromixer and BEKM.

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References