Effect of Geometry of the Grooves on the Mixing of Fluids in Micro Mixer Channel

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Abstract:-

Understanding the flow fields at the micro-scale is a key to develop methods of successfully mixing fluids for micro-scale applications. This paper investigates flow characteristics and mixing behavior of fluids in micro channel due to three different geometries in micro-channel. A Circular groove *micro mixer* has been designed and simulated. The geometry of the channel taken was rectangular with a dimension of 200µm wide, 200µm deep and 7.7 mm long. In first channel there were circular grooves and in the second channel there were rectangular grooves in the flow fields, while in the third geometry, there were triangular grooves. COMSOL software was used to investigate the flow characteristics within these microfluidic models for three different geometries. A species 2D model was created for three geometries and simulations were run in order to investigate the mixing behavior of two different fluids. Water and acrylene orange dye was used to simulate the effect of two different fluids. The results showed that the mixing behavior strongly depended on the channel geometry when other parameters such as fluid inlet velocity, viscosity and pressure of fluids were kept constant. In two geometries lateral pressure and swirling vortexes were developed which provided better mixing results.

Keywords:-

Micro-channel, Concentration, Micro-mixing & Grooves.

1. Introduction

Microfluidics is the study of fluid flow in geometries with one of the channel dimensions being of the micrometer scale. These geometries are built-up into circuits known as microfluidic chips. This technology has been the cause for much research, as it provides a means for carrying out key chemical assessment processes in the biomedical field (K. Samuel et al., 2003; H.A. Stone and K. Kim, 2001). This technology has many application in many different fields including pharmaceuticals cosmetics, medicine and biotechnology (K. Samuel et al., 2003; H.A. Stone and K. Kim, 2001; R. Kröger, 2006). Main applications of micro fluids at this stage include diagnostics, DNA sequencing, drug delivery, lab-on-a-chip applications, micro-reactors,

and fuel cells (K. Samuel et al., 2003; H.A. Stone and K. Kim, 2001; R. Kröger, 2006). One of the main challenges in microchannel is mixing where more than one fluid come together. It is difficult to get a uniform mixing in microsystem due to the laminar natural of the most micro flow. Processes involving mixing are profoundly concerned with the growth of various fields. Mixing exerts crucial influences on the reactions of combustion or catalysis, the efficiency of power mechanics, and the yields of chemical synthesis. Because of the expanding technology in micro-electro-mechanical systems (MEMS), investigations of fluids on a micro scale have increased to stimulate the development of micro-fluidic devices (Nguyen and Wereley, 2002). A classic mixing device for micro fluids is a micro mixer that enables rapid mixing with a small sample volume. In microfluidic systems, the system is dominated by laminar flow or viscous flow, depending on the Reynolds number. Laminar flow is natural under a situation with a small Reynolds number for which there is no violent convection to extend the interfacial area of micro fluids. Ottino (1989) hence explained that mechanisms of chaotic mixing involving stretching and folding, diffusion and breaking of fluids were advantageous to elongate a material interface, and then mixing between fluids is promptly achieved.

A current micro mixer operates either passively or actively (Hessel et al., 2005). Active micro mixers taking advantage of external energy input such as a timing-pulse input (Niu and Lee, 2003), electro wetting manipulation (Paik et al., 2003), and piezoelectric vibration (Liu et al., 2002), greatly disturb a flow field to achieve excellent mixing, but their disadvantage, because of elaborate fabrication, is that an active micro mixer is expensive and inconvenient for mass production. In contrast, a passive micro mixer entails less expense and more convenient fabrication than an active one but achieves desirable mixing without additional external support. Some approaches to chaotic mixing by passive micro mixers are briefly classified as follows.

(1) By means of the geometric structure of the channel design (serpentine, Liu et al., 2000; Yang and Lin, 2006 and zigzag, Mengeaud et al., 2002), patterned grooves dug at the bottom of channel (slanted, Stroock et al., 2002b and herringbone, Stroock et al., 2002a), and obstacles set inside the channel (Kim et al., 2004), transverse motion was induced to stir and to stretch the material interface of

fluids. Most geometric parameters were conducive to optimal designs and configurations have been explored widely (Stroock et al., 2002a; Aubin et al., 2005; Yang et al., 2005). Via Taguchi's method, Yang et al. (2005) explored the effects of the geometric parameters of a staggered herringbone mixer (SHM) on the mixing performance.

(2) The mechanisms of splitting and recombination repeated alternately to construct homogeneous chaotic mixing (Schwesinger et al., 1996; Schönfeld et al., 2004); this approach was suitable for the mixing of highly viscous fluids, such as polymer melts.

(3) The devices with overlapping channels utilized the mixing principles combining the effect of patterned grooves and split-and-recombination (Wang and Yang, 2006; Wang et al., 2007). Tumbling flow hence occurred that occurred that generate chaotic behavior, such as stretching and folding; as a result, mixing is reinforced in channel.

Recently, a wide variety of microfluidic devices have been developed for efficient cell separation. Micro-pillar arrays were used by Tan et al. (2009) and Mohamed et al.(2009) to isolate circulating tumour cells from blood. The rapid mixing was realized by the collision of microfluidic segments, which were divided into several radial streams at the center of mixer. Ehrfeld et al.(1999) fabricated an inter digital micromixer with channel characteristic size of only 25 mm, and the fast mixing was obtained by using the principle of multi lamination. Wong et al.(2004) demonstrated that the swaying of the fluids in the complicated twisted microchannel caused chaotic advection, hence improved the micromixing performance. The excellent micromixing performance could be achieved by flow splitting, recombination, and rearrangement in split-and-recombine micromixers (Sch¨onfeldetal.,2004). However, it is difficult to manufacture these micromixers due to the complexity of their structure, and their practical application usually is scarce. T-shaped microchannel is easy to design and manufacture, so it is widely used in laboratory. Soleymani et al.(2008) carried out the numerical and experimental investigations of liquid mixing in T-shaped microchannels. Their simulation results proved that the occurrence and the development of vortices in the T-junction of the microchannel were essential for the good mixing performance, which both strongly depended on the flow.

Material and geometry

The model was designed in COMSOL for simulation. The geometry consists of various types of grooves (circular, triangular and rectangular). The Fig.1 shows the geometry of model. The channel has 200 um width, 200 um depth and 7.7 mm length. Circular grooves has radius of 100 um and rectangular and triangular grooves have also same cross section. The turning has inner radius 550 um and outer radius 750 um. The two inlets are at angle of 60 degree in between them. The grooves are useful in this geometry for mixing as it form vortices in the flow which helps in proper mixing. There are two fluids which are flowing through this channel. One of the fluids is water and another is acrylene orange dye. In COMSOL, we have taken water and a fluid whose properties resembles with acrylene orange dye.

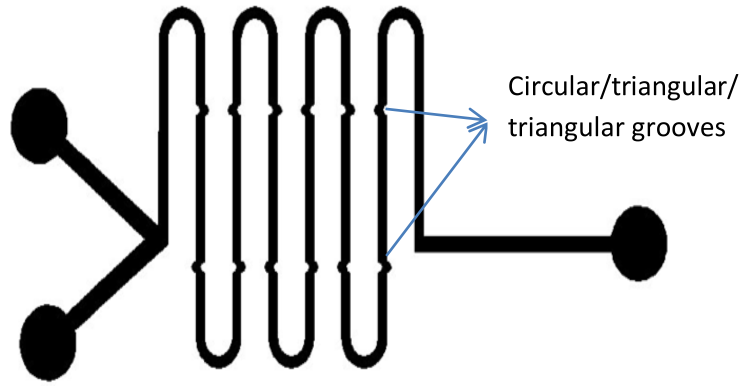


Fig.1 Geometry of Micro channel having two circular grooves in each turning.

The input parameters are inlet Volume flow rate, input concentration and Isotropic diffusion coefficient. The inlet volume flow rate is 10µl/min. the input concentration of both the liquids is 20 kg/m^3 and isotropic diffusion coefficient is 10^{-10}m^2/s.

Analysis and Discussion

We have taken different cases for analyzing. We have plotted concentration vs length of channel graphs for various cases and investigated the effects of grooves on the mixing pattern. Then with the help of these graphs we estimated the optimum length of the channel for mixing the fluids at the micro-level.

Case 1: Channel with one triangular, one rectangular and one circular groove separately before each bend.

In triangular case, we can see that mixing is almost completed at 60,000 µm and after that the concentration of mixed fluid is almost constant. So, it appears that it is the optimum length which is required in this case for proper mixing. For rectangular shaped grooves, the mixing appears to be proper after 57,500 µm and for the circular shaped grooves; it is approx. at 55,000 µm. The mixing of channel containing circular grooves, rectangular grooves and triangular grooves shown in Fig. 2, Fig. 3 and Fig. 4 respectively.

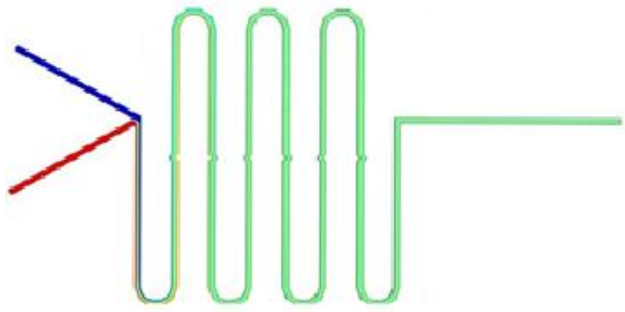


Fig. 2: Mixing behavior of two fluids in a micro channel having one circular groove.

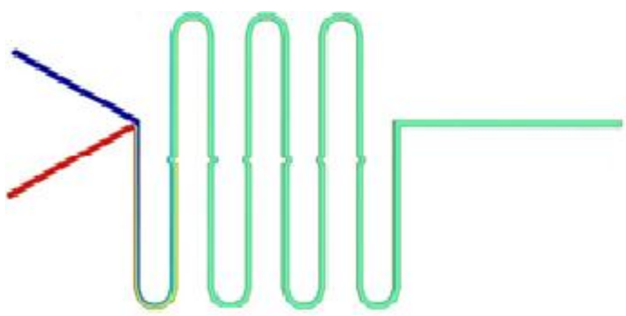


Fig. 3: Mixing behavior of two fluids in a micro channel having one rectangular groove.

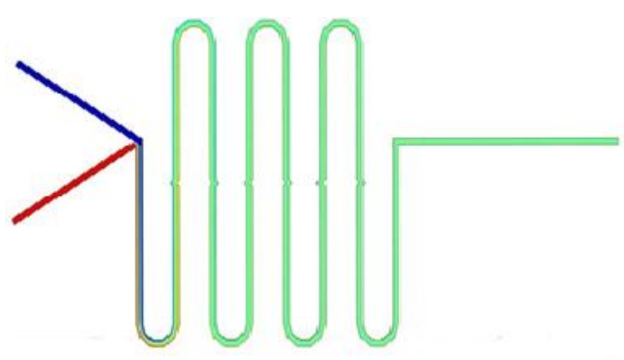
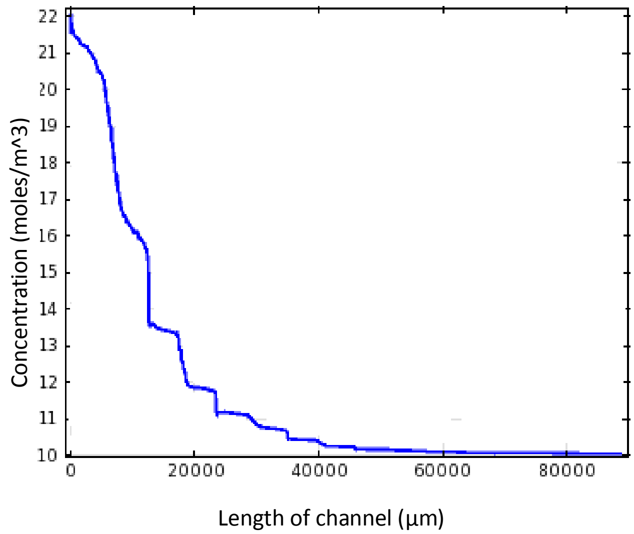
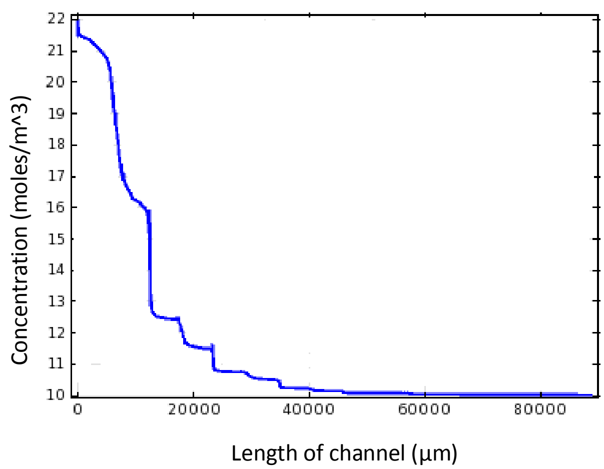


Fig. 4: Mixing behavior of two fluids in a micro channel having one triangular groove.

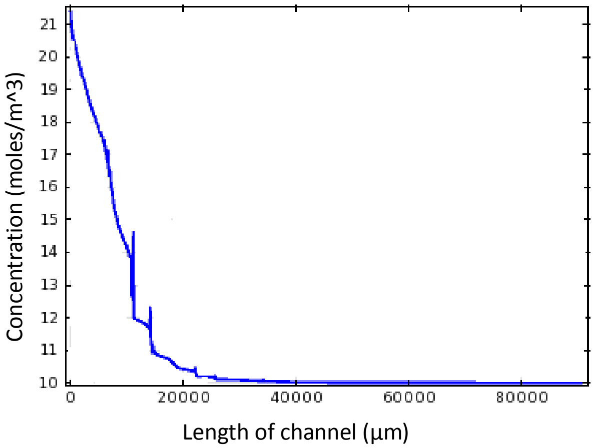


Graph 1:- The effect of single triangular groove on concentration of mixing in microchannel is having input velocity 20 µl/min along the channel length.

As shown in the graph, as increasing the arc length the concentration of acrylene orange is reduces. Upto 20000µm the concentration rapidly decreases and after that its gradually decrease and at 80000 µm its becomes constant and reaches concentration of 10 mol/m³.



Graph 2:– The effect of single circular groove on concentration of mixing in microchannel is having input velocity 20 µl/min along the channel length.



Graph 3:– The effect of single rectangular groove on concentration of mixing in microchannel having input velocity 20 µl/min along the length of the channel.

Case 2: Channel with two rectangular, two triangular and two circular grooves separately before each bend.

As the number of grooves are increasing in these cases so mixing should be more proper at smaller length than previous case 1. For, rectangular case mixing length is 40,000 µm, while it is 45,000 µm for the triangular case and approx. 40,000 µm of circular case. So, it can be analyze that the mixing is almost same in circular and rectangular cases. The mixing of channel containing circular grooves, rectangular grooves and triangular grooves shown in Fig. 5, Fig. 6 and Fig. 7 respectively.

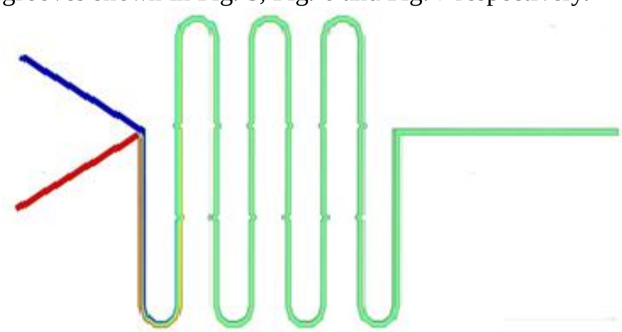


Fig. 5: Mixing behavior of two fluids in a micro channel having two circular grooves.

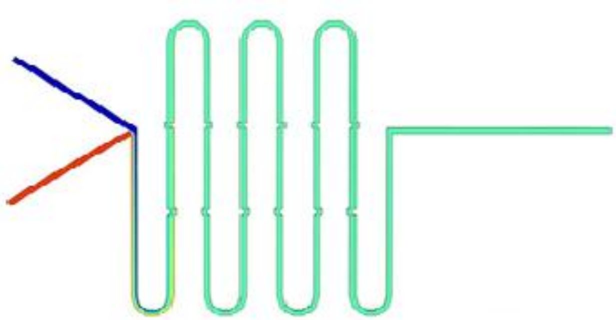


Fig. 6: Mixing behavior of two fluids in a micro channel having two rectangular grooves.

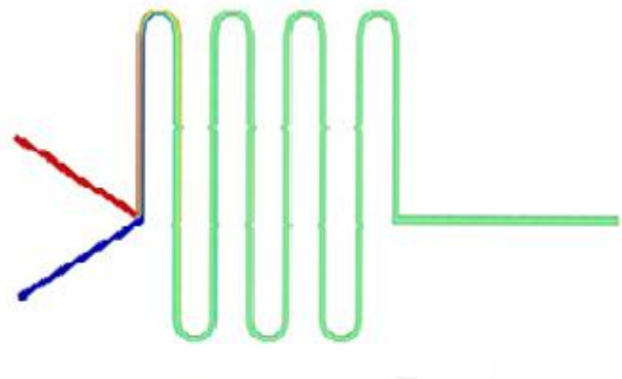
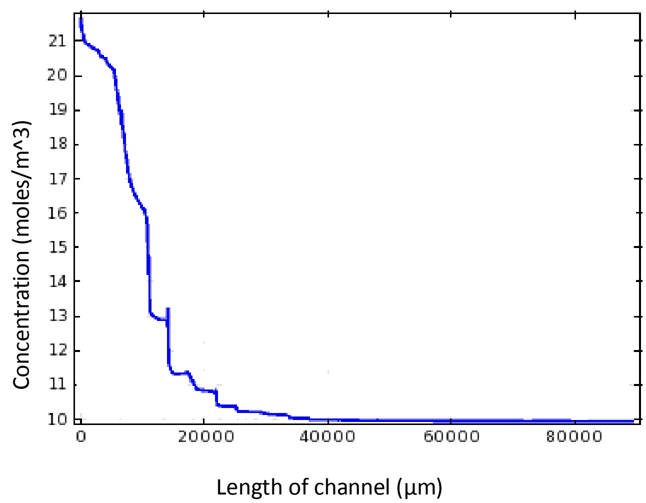
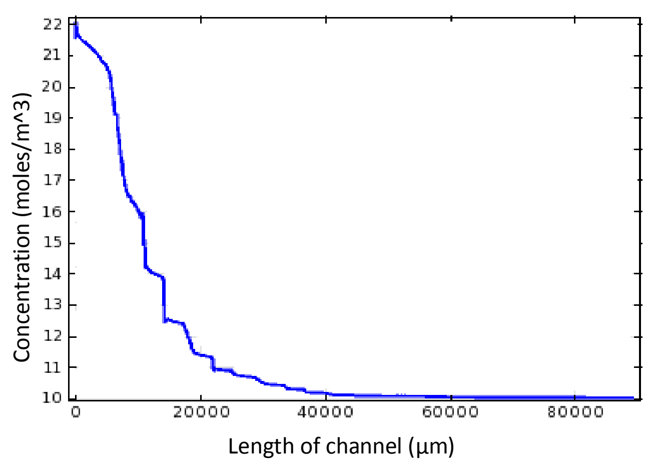


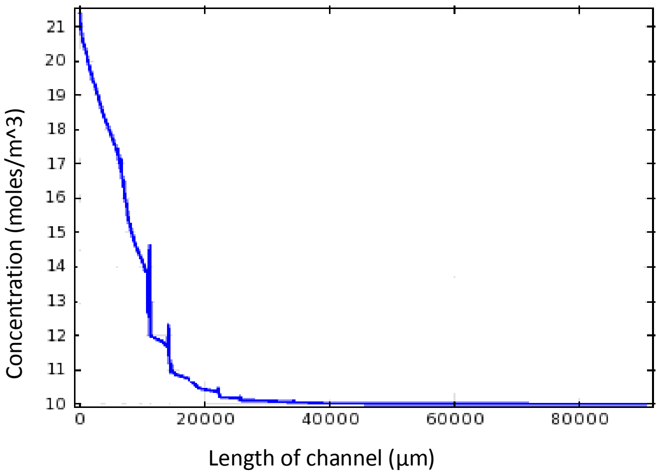
Fig. 7: Mixing behavior of two fluids in a micro channel having two triangular grooves.



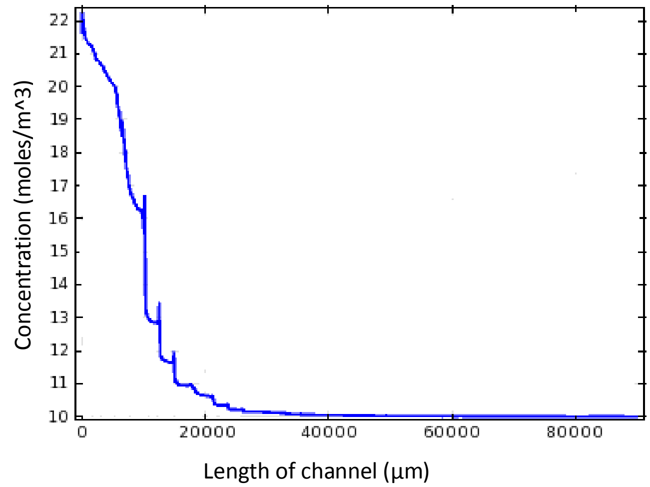
Graph 4:– The effect of two circular grooves on concentration of mixing in microchannel is having input velocity 20 µl/min along the channel length.



Graph 5:– The effect of two triangular grooves on concentration of mixing in microchannel is having input velocity 20 µl/min along the channel length.



Graph 6:– The effect of two rectangular grooves on concentration of mixing in microchannel is having input velocity 20 µl/min along the channel length.



Graph 7:– The effect of three circular grooves on concentration of mixing in microchannel having input velocity 20 µl/min along the channel length.

<u>Case 3:</u> Channel with three circular grooves before each bend.

Here, as we further increase the number of grooves before each turning. So, mixing will be better. In this case proper mixing appears to take place at 35,000

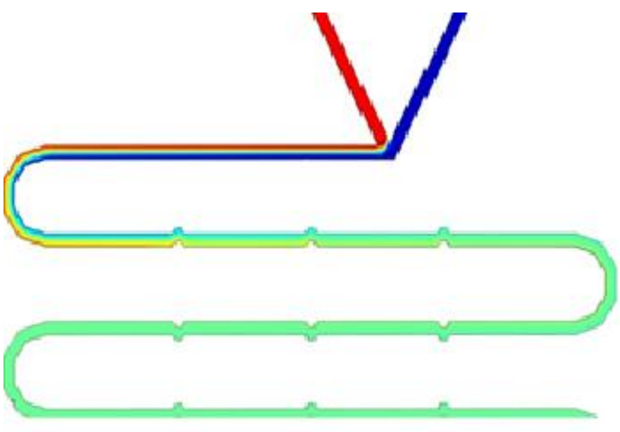


Fig. 8: Mixing behavior of two fluids in a micro channel having three circular grooves.

<u>Case 4:</u> Channel with one circular, one rectangular and one triangular simultaneously before each bend.

In this case also proper mixing take place at approx. 35,000 µm roughly. But when we will analyze it, we will find that mixing in case 3 is better than that of this case. Therefore, it appears that circular grooves are better in comparison to all the three types of grooves.

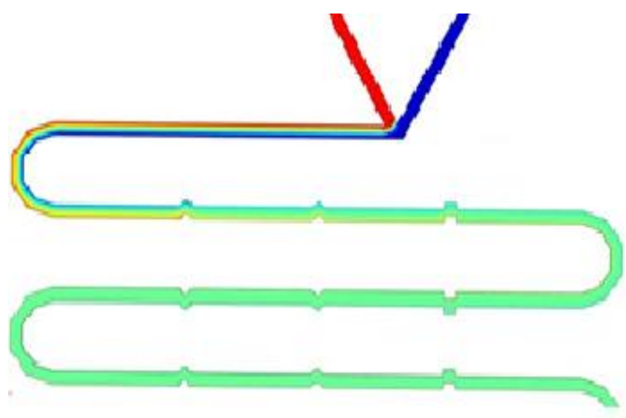
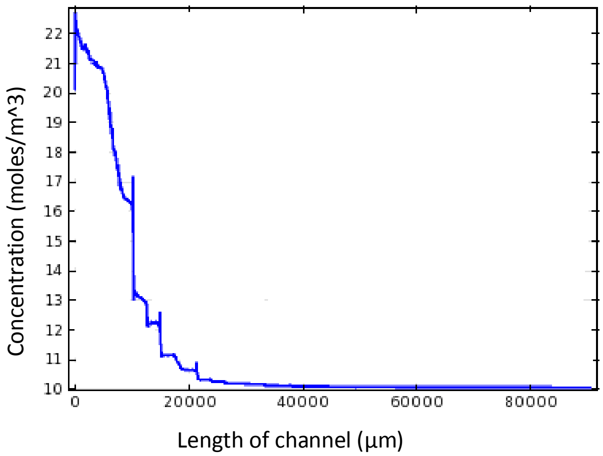


Fig. 9: Mixing behavior of two fluids in a micro channel having one triangular, rectangular and circular groove.



Graph 8:– The effect of one triangular, rectangular and circular groove simultaneously on concentration of mixing in microchannel is having input velocity 20 µl/min along the channel length.

Conclusions:

(1) When we are increasing the number of grooves, the mixing length for proper mixing is decreasing.
(2) Mixing is affected by the geometry of grooves. Better mixing is obtained for circular groove case having three circular grooves before bend. The optimum length for mixing is found to be 35,000 µm.

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