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LIQUIDS MIXING OPTIMIZATION IN MICROCHANNELS

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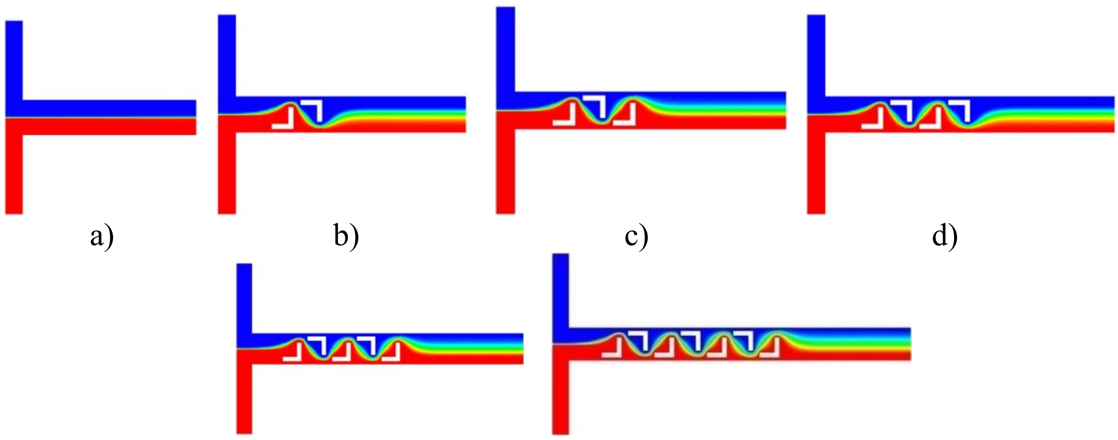
Mixing of microscopic quantities of a liquid has great value in many applications: chemical microreactors, analyzers of chemical and biological substances and many others. As characteristic value of Reynolds‘s number for microchannels about 1 speed of mixing in them is defined basically by molecular diffusion. And it is a very slow process, various ways of improvement of mixing therefore are applied.

One of the ways of an intensification of mixing in microchannels is application of various inserts. In the given work mixing in the T-shaped microchannel with L-shaped inserts is considered.

In the first series of numerical experiments Reynolds's and Pecle’s numbers were fixed and the amount of inserts varied. On figures 1a-1f the qualitative picture of mixing of liquids in the channel (without inserts, with two, three, four, five and seven inserts) is shown. Reynolds's number in the given series of calculations was equaled 2, Pecle’s number – 5000. Quantitative results of calculations are submitted in table 1.



a) b) c) d)

e) f)

Figure 1 – Mixing of two liquids in the T-shaped microchannel: a) without L-shaped inserts; b) with two L-shaped inserts; c) with three L-shaped inserts; d) with four L-shaped inserts; e) with five L-shaped inserts; f) with seven L-shaped inserts

Table 1 – Results of numerical modelling of mixture of two liquids in the T-shaped microchannel with various amount of L-shaped inserts

Amount of inserts	Pressure difference , Pa	Mix, %	Efficiency of mixing, I_n/I_0	Amplification of pressure difference, p_n/p_0
0	8,905	4,264	1	1
2	22,057	20,922	4.907	2,477
3	29,869	22,811	5.350	3,354
4	37,686	24,816	5.820	4,232
5	45,503	26,693	6.260	5,110
7	61,136	30,876	7.241	6,865

In the second series of calculations the number of inserts has been fixed, and Reynolds's and Pecle’s numbers varied. As a result of numerical modelling it has been established, that with the increase in Reynolds’s number both mixture and pressure difference grow, but efficiency of mixture depends on Pecle’s number only, and difference of pressure remains constant.

In figures 2a-2f visual display of mixing of liquids in the T-shaped microchannel with four and five inserts with various Reynolds's and Pecle's numbers is shown.

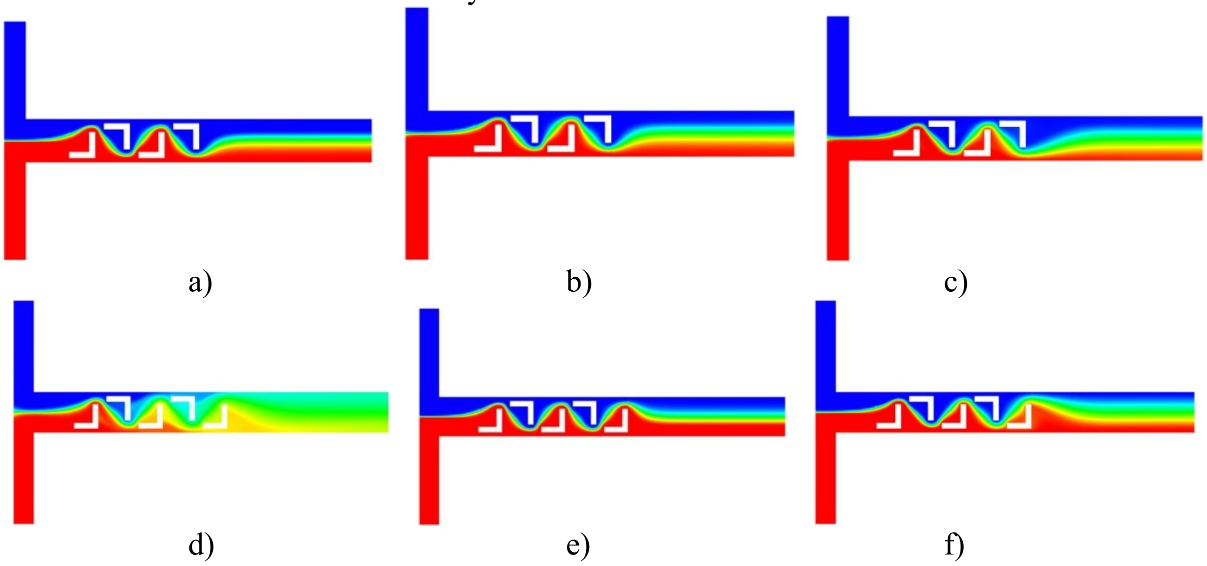


Figure 2 - Mixing of two liquids in the T-shaped microchannel: a) with four L-shaped inserts, Re = 0,5 and Pe = 5000; b) with four L-shaped inserts, Re = 2 and Pe = 500; c) with four L-shaped inserts, Re = 10 and Pe = 500;dr) with five L-shaped inserts, Pe = 10 and Pe = 100; e) with five L-shaped inserts, Re = 0,01 and Pe = 20000; f) with five L-shaped inserts, Re = 10 and Pe = 20000;

Other variant of intensification is a mixture of liquids in an S-type micromixer with rectangular section. Geometry of the channel with three sections and a qualitative picture of mixing in the given channel are shown in figure 3. Calculation grid contained about 150000 units. Reynolds's number was set equal to 4, Pecle's number – 5000.

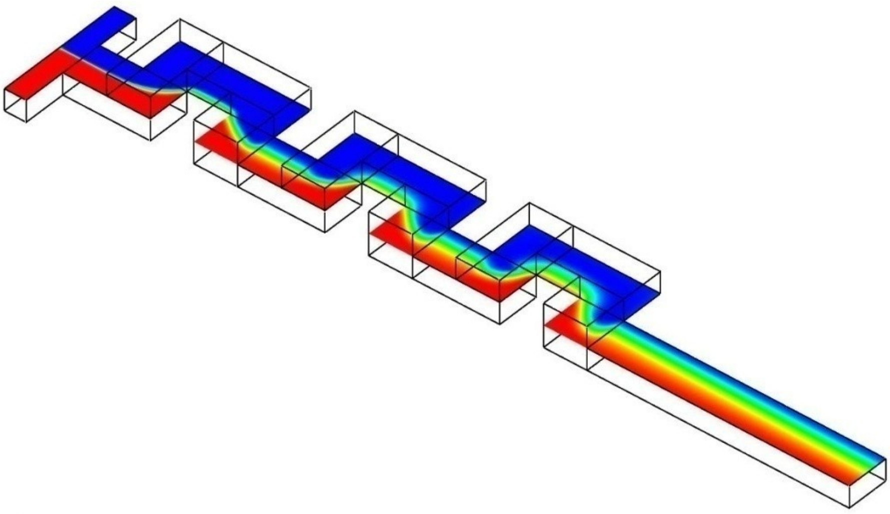


Figure 3 – Geometry of an S-type micromixer with three rectangular sections.

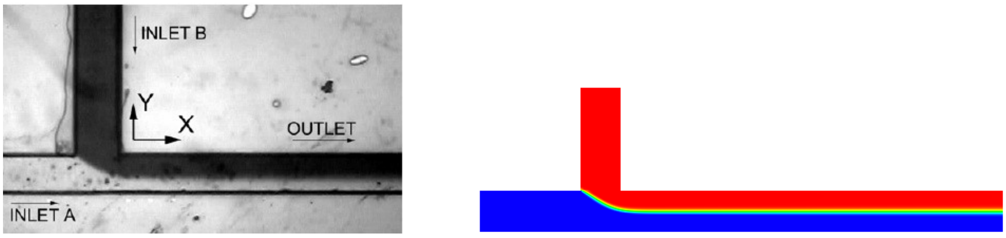
Calculations were carried out for S-type micromixer with one, two, three, four and eight sections. Results of the calculations were compared to the results of mixture in the direct channel of rectangular section of the similar length. It is shown in table 2. Apparently from the table mixing in S-type micromixer is much better, and difference of pressure is even less, than in the direct channel. It can be explained by the fact that in the places of a bend of micromixer the area of section is twice as big, than in its direct sites.

Table 2 – Results of numerical modelling of two liquids mixing in the curved microchannel of rectangular section

Amount of sections	Pressure difference in the curved channel, Pa	Mixing in the curved channel, %	Pressure difference in the direct channel, Pa	Mixing in the direct channel, %	Mixing in the direct channel (analytics), Pa
1	283,6	24,40	355,5	8,26	363,3
2	402,9	32,44	546,7	10,26	559,0
3	522,0	37,39	737,7	11,95	754,6
4	641,3	43,70	930,3	13,43	950,2
8	1118	58,74	1693	18,23	1733

Except for passive methods of mixture where process is intensified due to features of the channel geometry, there are also active methods of mixture where the intensification occurs under action of external factors (electromagnetic, acoustic). In the given work the way of an intensification concerned with periodic changes of the liquid consumption on an inlet in the microchannel has been considered. Comparison of passive and active methods of liquids mixing in a micromixer of T-type has been carried out.

The channel geometry is shown in figure 4, width of the microchannel – 200 microns, thickness – 100 microns. The left and the right inlets have identical lengths – 500 microns. Length of the mixing channel – 2000 microns. At passive mixing on the top inlet of the microchannel the tinted liquid with averageconsumption speed 1 mm/s is delivered, on the left inlet with the same speed the pure liquid with the following physical properties is delivered: density – 1000 kg/m^3, viscosity – 0.000667 Pa×s, diffusion factor of paint in a pure liquid – 7×10^{-11} m^2/s.



a) b)

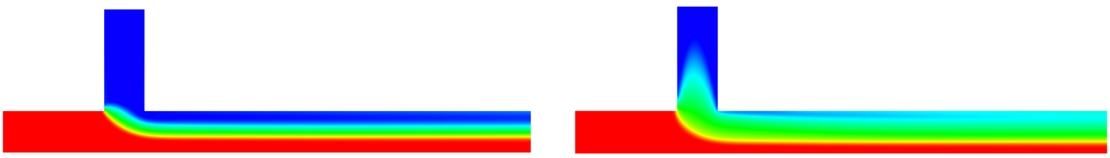
Figure 4 – Channel geometry: a) experiment; b) calculation

As you can see, the mixing there is very bad. Mixing efficiency at stationary current on an outlet from the mixer (on distance 2000 microns from a point of streams merge) makes 9,9 %. Pressure difference between the top inlet and the outlet equals ΔP = 5,149 Pa.

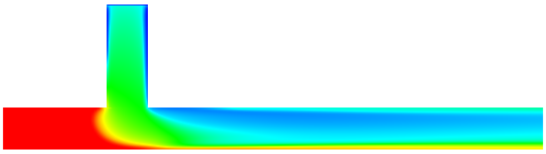
At active mixing on the left inlet averageconsumption speed of a liquid was set constant and equal to 1 mm/s. Averageconsumption speed on the top inlet was set as follows: $V=1mm/s+A\times\sin(2\pi f\times t)$, where f – frequency of speed pulsations on the inlet, A – amplitude of pulsations. Frequency and amplitude of speed pulsations in our calculations was varied as follows: A = 1, 2, 5, 10 mm/s; f = 0.05, 0.1, 1, 2, 5, 10 Hz.

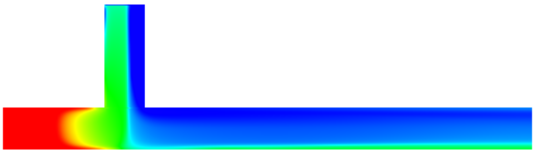
In figures 5a-5d the results of calculation – isolines of average on time concentration of paint are represented.

Dependence of average mixing efficiency from frequency and amplitude of speed pulsations on the inlet is resulted in figure 6. Apparently, with growth of speed pulsations frequency mixing efficiency grows, reaching the maximum in the area of 1-2 Hz, then slowly falls. With growth of speed pulsations amplitude mixing efficiency also grows, reaching a maximum at amplitude 5 mm/s, and then decreases.



a) b)





c) d)

Figure 5 – Isolines of average on time concentration of paint: a) *f* = 1 Hz, A = 1 mm/s; b) *f* = 1 Hz, A = 2 mm/s; c) *f* = 1 Hz, A = 5 mm/s; d) *f* = 1 Hz, A = 10 mm/s;

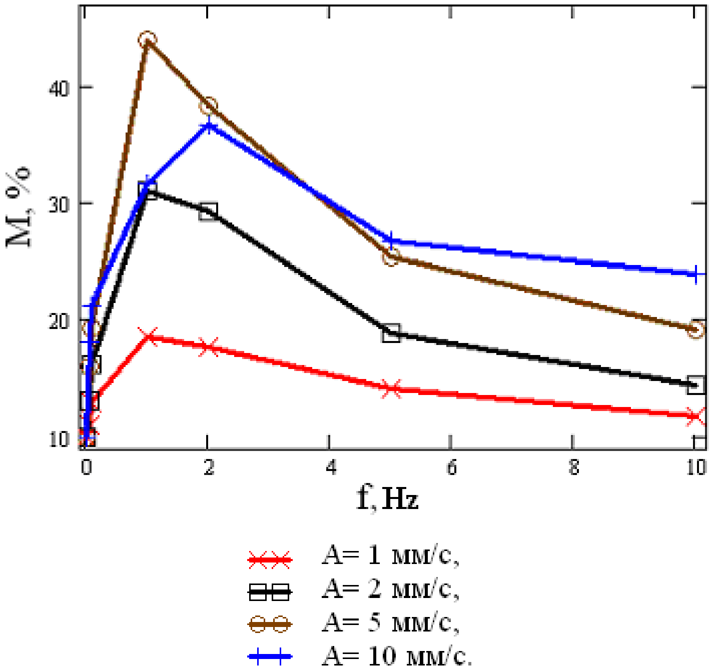


Figure 6 – Dependence of average mixing efficiency from frequency and amplitude of speed pulsations on the inlet.