4.3. Mixing of Liquids Differing in Viscosity and Density.

Two types of experiments were conducted in the on-line mixer with liquids differing in viscosity and density:

- more viscous liquid of higher density was fed centrally from the dosing pipe and the less viscous and less dense liquid was fed annularly,
- less viscous liquid of slightly higher density was fed centrally and the more viscous and less dense liquid was fed annularly.

Tables 4.III and 4.V show compositions and physical properties of the solutions used in these experiments. Volumetric flow rates, mean velocities, Reynolds number values are presented in tables 4.IV and 4.VI.

Table 4.III. Compositions and properties of the test solutions; more viscous liquid in the core.

liquid	starch syrup [weight %]	I_2 [mol/dm^3]	$Na_2S_2O_3$ [mol/dm^3]	μ [Pa·s]	ρ [g/cm^3]
A	74.0	0.0112	0.0	0.128	1.294
B	0.0	0.0	0.005	0.001	1.000

Table 4.IV. Flow rates, mean velocities and Reynolds numbers; more viscous liquid in the core.

exp. no.	Q_1 [cm^3/s]	$\bar{w}_1$ [cm/s]	Re_1	Q_2 [cm^3/s]	$\bar{w}_2$ [cm/s]	Q_2/Q_1	$\bar{w}_{out}$ [cm/s]
1	0.0287	1.342	0.224	2.863	0.2293	99.76	23.01
2	0.0569	2.661	0.444	2.846	0.2279	50.02	23.10
3	0.1145	5.355	0.894	2.710	0.2170	23.67	22.48
4	0.2895	13.54	2.260	2.509	0.2009	8.667	22.27

Table 4.V. Compositions and properties of the test solutions; less viscous liquid in the core.

liquid	starch syrup [weight %]	I_2 [mol/dm^3]	$Na_2S_2O_3$ [mol/dm^3]	μ [Pa·s]	ρ [g/cm^3]
A	0.0	0.0150	0.0	0.001	1.363
B	80.78	0.0	0.0098	0.424	1.329

Table 4.VI. Flow rates, mean velocities and Reynolds numbers; less viscous liquid in the core.

exp. no.	Q_1 [cm^3/s]	$\bar{w}_1$ [cm/s]	Re_1	Q_2 [cm^3/s]	$\bar{w}_2$ [cm/s]	Q_2/Q_1	$\bar{w}_{out}$ [cm/s]
5	0.01002	0.4686	10.54	1.156	0.0926	115.4	9.279
6	0.02060	0.9634	21.67	1.134	0.0908	55.05	9.188
7	0.04659	2.179	49.00	1.122	0.0899	24.08	9.299
8	0.08486	3.969	89.26	1.126	0.0902	13.27	9.636
9	0.2254	10.54	237.0	1.290	0.1003	5.723	12.06

In the first group of experiments with the more viscous liquid flowing in the core, the flow was always stable. The changes of shape of the central stream due to entrance effects and in the cone-shaped section of the mixer nozzle were very small, as shown in figures 4.5abcd. In some cases deflection of the iodine stream from the mixer axis was observed.

Results of a completely different character were obtained in the second group of experiments, when the less viscous liquid was flowing in the core. Figures 4.6abcd show that the central stream forms in these cases a line of ellipsoids. At very small flow rates $\mathbf{Q_1}$ the cylindrical thread, formed initially, breaks up after some time into the line of ellipsoids (figure 4.6a). In the conical part of the mixer the segregated structures are partially or completely destroyed due to stretching action of the surrounding liquid. However, in the cylindrical outlet of the mixer nozzle the line of ellipsoids can be formed again (figure 4.6e). The ellipsoids swell substantially when the flow rate $\mathbf{Q_1}$ is increased; for relatively higher flow rates $\mathbf{Q_1}$ the initial stable flow can be hardly observed (figures 4.6bc). Further increase of the flow rate of the less viscous liquid destabilizes the periodic structures; their shape is deformed and they start to oscillate (figure 4.6d). The flows within the structure and between the neighboring structures can also be observed. At very high dosing speeds the ellipsoids are losing their identity and the central stream is completely destabilized (figure 4.6e).

It should be noted that break-up of the central stream into drops was not observed; this is so, because there is no surface interfacial tension between the mixed liquids. Some tests were performed with single drops of less viscous iodine solution immersed in more viscous thiosulfate solution flowing through the system. When these drops were allowed to pass slowly through the nozzle throat, formation of the periodic structures was observed, similarly as in figure 4.6f. This fact indicates that the phenomena of formation of the segregated structures before and after the conical part of the mixer nozzle are independent.

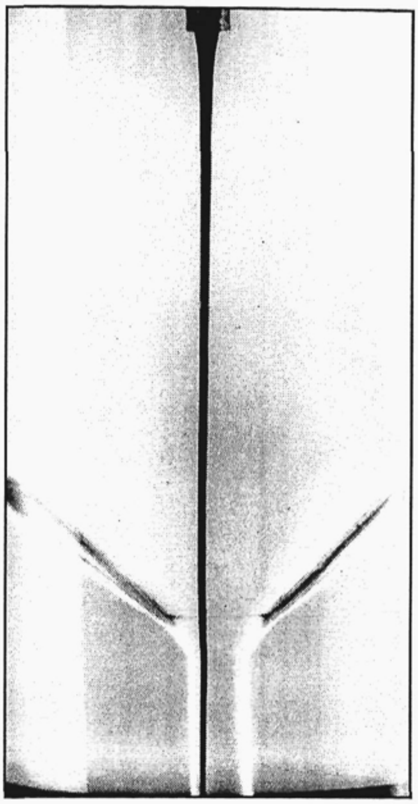

Figure 4.5a. Experiment number 1.

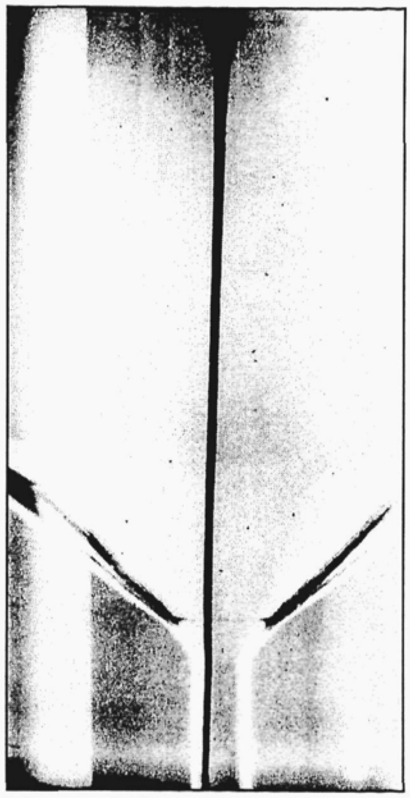

Figure 4.5b. Experiment number 2.

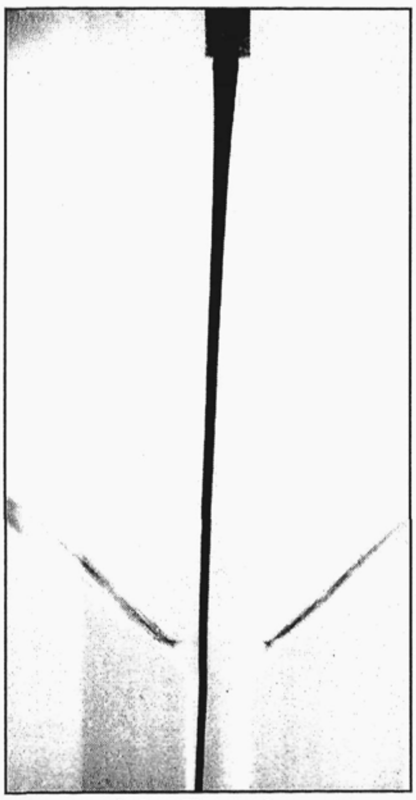

Figure 4.5c. Experiment number 3.

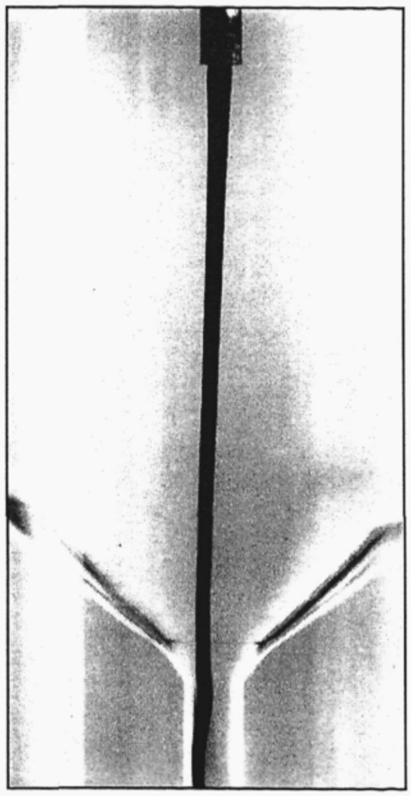

Figure 4.5d. Experiment number 4.

Mixing of liquids differing in viscosity and density; more viscous and more dense liquid in the core.

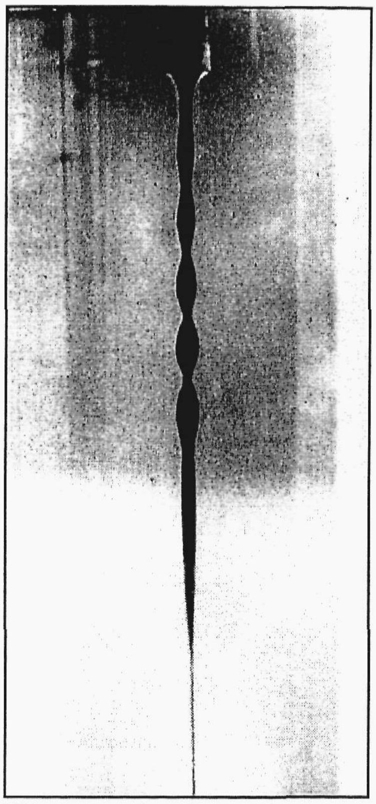

Figure 4.6a. Experiment number 5.

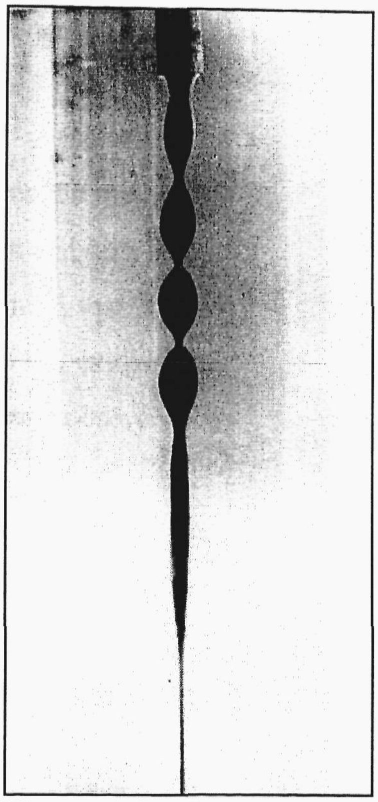

Figure 4.6b. Experiment number 6.

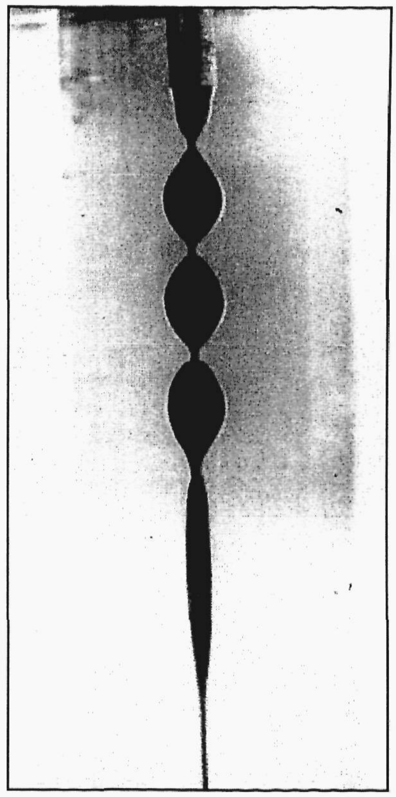

Figure 4.6c. Experiment number 7.

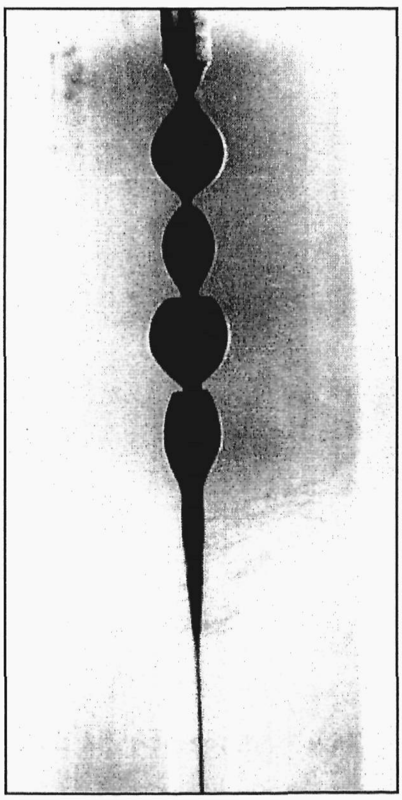

Figure 4.6d. Experiment number 8.

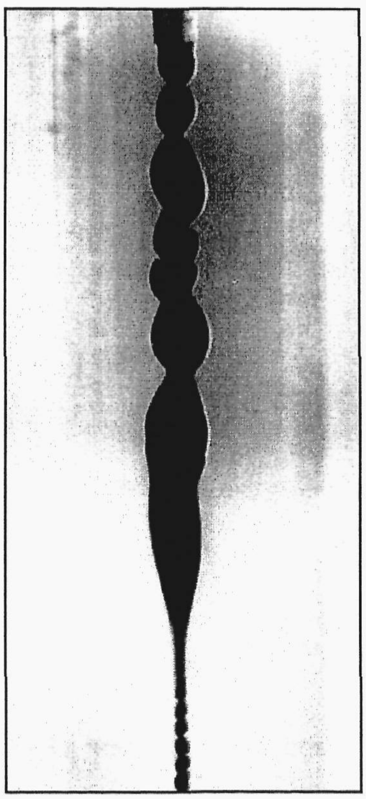

Figure 4.6e. Experiment number 9.

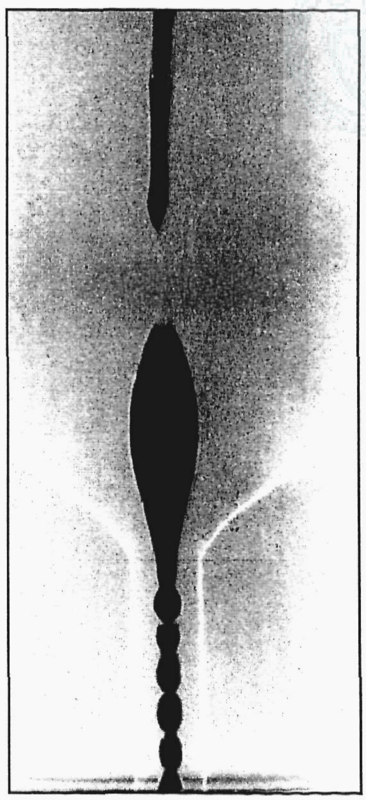

Figure 4.6f. Single drop of less viscous liquid.

Mixing of liquids differing in viscosity and density; less viscous and more dense liquid in the core.