

Enhanced Fluid Mixing in Microchannels Using Levitated Magnetic Microrobots: A Numerical Study

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Table SI 1 : Mixing Efficiency, Standard Deviation Percentage (STD%), Homogeneity Index (HI), and Quality Index across Different Levitation Heights and Panels over Time

		PANEL I						PANEL II						PANEL III					
	t(s)	25	50	100	150	200	250	25	50	100	150	200	250	25	50	100	150	200	250
Mixing Eff	0.00	99.369	99.437	99.110	99.328	98.250	99.890	99.801	99.660	99.603	99.911	99.501	98.943	99.821	99.210	99.688	99.703	99.890	99.200
	0.25	99.629	99.978	99.548	96.411	96.851	99.293	96.122	95.466	99.817	98.883	99.708	97.900	93.092	92.690	97.581	95.983	96.689	95.571
	0.50	99.538	99.402	99.825	96.589	97.438	99.140	99.636	99.665	99.686	97.259	97.661	98.992	97.073	97.745	99.629	99.232	99.711	97.664
	1.00	99.458	99.662	99.954	97.898	98.584	98.156	99.936	99.689	99.463	98.268	98.784	98.062	99.747	99.607	99.447	98.163	98.575	98.243
	1.50	99.556	99.837	99.806	98.728	99.521	97.581	99.858	99.454	99.293	99.261	99.722	97.411	99.781	99.405	99.269	99.169	99.545	97.538
	2.00	99.610	99.968	99.715	99.427	99.955	97.152	99.795	99.297	99.207	99.914	99.680	96.999	99.712	99.237	99.151	99.891	99.762	97.064
	2.50	99.661	99.935	99.648	99.716	99.544	96.937	99.751	99.203	99.130	99.666	99.295	96.734	99.663	99.121	99.076	99.645	99.322	96.761
	3.00	99.679	99.828	99.648	99.940	99.363	96.741	99.728	99.142	99.130	99.401	99.056	96.565	99.631	99.059	99.076	99.349	99.044	96.566
STD %	0.00	48.376	50.378	47.990	49.403	47.664	41.683	51.835	52.898	53.057	50.712	51.737	44.702	46.963	49.217	48.318	49.832	47.085	40.132
	0.25	2.205	2.242	2.174	2.450	2.924	1.415	4.365	3.753	1.090	3.749	4.546	3.502	19.006	18.735	3.333	17.357	17.160	14.035
	0.50	2.176	2.069	2.134	2.294	2.559	1.310	1.023	0.921	1.153	1.249	1.638	0.614	3.049	3.289	0.966	3.232	3.026	2.193
	1.00	2.230	2.037	2.113	2.208	2.425	1.298	1.182	1.021	1.142	1.311	1.656	0.638	0.947	0.822	0.995	1.152	1.515	0.522
	1.50	2.187	2.030	2.110	2.163	2.388	1.245	1.186	1.008	1.136	1.275	1.589	0.615	1.023	0.852	0.983	1.124	1.477	0.512
	2.00	2.224	2.014	2.100	2.116	2.312	1.254	1.185	1.003	1.128	1.228	1.551	0.595	1.023	0.837	0.977	1.080	1.430	0.493
	2.50	2.184	2.013	2.102	2.106	2.314	1.219	1.179	0.993	1.127	1.211	1.520	0.587	1.019	0.831	0.970	1.049	1.403	0.483
	3.00	2.219	2.007	2.102	2.073	2.262	1.236	1.180	0.995	1.127	1.188	1.508	0.579	1.017	0.824	0.970	1.032	1.383	0.477
Homogeneity	0.00	51.930	49.900	52.430	50.260	51.490	58.270	48.060	47.280	46.730	49.330	48.000	54.820	53.120	51.170	51.530	50.320	52.860	59.540
	0.25	97.800	97.760	97.820	97.460	96.980	98.600	95.800	96.410	98.910	96.290	95.440	96.570	82.220	82.540	96.750	83.310	83.390	86.560
	0.50	97.810	97.920	97.860	97.620	97.370	98.700	98.980	99.080	98.850	98.720	98.320	99.390	97.040	96.780	99.040	96.740	96.970	97.860
	1.00	97.760	97.960	97.890	97.740	97.540	98.730	98.820	98.980	98.860	98.670	98.320	99.370	99.060	99.180	99.010	98.830	98.460	99.490
	1.50	97.800	97.970	97.890	97.810	97.600	98.780	98.820	99.000	98.870	98.720	98.410	99.400	98.980	99.150	99.020	98.870	98.520	99.500
	2.00	97.770	97.990	97.910	97.870	97.690	98.780	98.820	99.000	98.880	98.770	98.450	99.420	98.980	99.170	99.030	98.920	98.570	99.520
	2.50	97.810	97.990	97.910	97.890	97.700	98.820	98.820	99.010	98.880	98.790	98.490	99.430	98.980	99.180	99.040	98.950	98.610	99.530
	3.00	97.770	98.000	97.910	97.930	97.750	98.800	98.820	99.010	98.880	98.820	98.510	99.440	98.990	99.180	99.040	98.970	98.630	99.540
Quality Index	0.00	75.649	74.669	75.770	74.794	74.870	79.080	73.930	73.470	73.167	74.620	73.751	76.882	76.470	75.190	75.609	75.011	76.375	79.370
	0.25	98.714	98.869	98.684	96.936	96.916	98.947	95.961	95.938	99.364	97.586	97.574	97.235	87.656	87.615	97.165	89.647	90.040	91.065
	0.50	98.674	98.661	98.842	97.105	97.404	98.920	99.308	99.372	99.268	97.990	97.990	99.191	97.056	97.262	99.335	97.986	98.341	97.762
	1.00	98.609	98.811	98.922	97.819	98.062	98.443	99.378	99.335	99.161	98.469	98.552	98.716	99.404	99.393	99.229	98.497	98.518	98.867
	1.50	98.678	98.903	98.848	98.269	98.561	98.181	99.339	99.227	99.082	98.990	99.066	98.406	99.380	99.278	99.144	99.019	99.033	98.519
	2.00	98.690	98.979	98.812	98.649	98.823	97.966	99.308	99.149	99.043	99.342	99.065	98.209	99.346	99.203	99.090	99.406	99.166	98.292
	2.50	98.736	98.962	98.779	98.803	98.622	97.878	99.286	99.106	99.005	99.228	98.893	98.082	99.322	99.151	99.058	99.297	98.966	98.145
	3.00	98.724	98.914	98.779	98.935	98.556	97.770	99.274	99.076	99.005	99.110	98.783	98.002	99.310	99.119	99.058	99.160	98.837	98.053

Table SI 2 : Mixing Efficiency, Standard Deviation Percentage (STD%), Homogeneity Index (HI), and Quality Index across Different θ and Panels over Time

		PANEL I					PANEL II					PANEL III				
	t(s)	0°	1°	2°	3°	4°	0°	1°	2°	3°	4°	0°	1°	2°	3°	4°
Mixing Eff	0.00	99.328	90.992	91.210	91.207	90.983	99.911	99.081	99.097	99.097	99.090	99.703	98.814	98.640	98.640	98.753
	0.25	96.411	89.698	89.140	89.087	88.869	98.883	94.317	94.449	94.306	94.528	95.983	98.494	98.603	98.507	98.688
	0.50	96.589	91.069	91.231	91.291	91.184	97.259	91.565	91.472	91.496	91.533	99.232	93.667	93.671	93.662	93.726
	1.00	97.898	94.070	94.332	94.338	94.272	98.268	94.322	94.305	94.330	94.380	98.163	94.047	94.029	94.063	94.116
	1.50	98.728	95.821	96.101	96.138	96.084	99.261	96.322	96.326	96.349	96.420	99.169	96.195	96.210	96.228	96.302
	2.00	99.427	96.866	97.120	97.112	97.087	99.914	97.439	97.444	97.448	97.527	99.891	97.455	97.476	97.491	97.573
	2.50	99.716	97.350	97.596	97.618	97.580	99.666	98.040	98.007	98.016	98.114	99.645	98.169	98.168	98.171	98.272
	3.00	99.940	97.693	97.906	97.891	97.887	99.401	98.371	98.335	98.329	98.430	99.349	98.537	98.525	98.527	98.633
STD %	0.00	49.403	53.122	53.153	53.153	53.132	51.835	56.707	56.683	56.683	56.703	46.963	54.960	55.401	55.401	55.143
	0.25	2.450	4.447	5.456	5.437	5.439	4.365	12.112	12.660	12.662	12.485	19.006	23.910	24.466	24.454	24.335
	0.50	2.294	3.187	3.554	3.554	3.479	1.023	2.730	3.031	3.079	2.993	3.049	6.089	6.484	6.451	6.379
	1.00	2.208	3.007	3.190	3.205	3.191	1.182	2.765	3.006	3.053	2.979	0.947	2.550	2.765	2.816	2.744
	1.50	2.163	2.938	3.133	3.154	3.081	1.186	2.552	2.751	2.800	2.731	1.023	2.413	2.614	2.652	2.587
	2.00	2.116	2.823	2.980	3.002	2.979	1.185	2.437	2.654	2.694	2.613	1.023	2.223	2.425	2.468	2.393
	2.50	2.106	2.833	3.027	3.044	2.959	1.179	2.362	2.557	2.607	2.535	1.019	2.126	2.329	2.369	2.296
	3.00	2.073	2.760	2.922	2.946	2.916	1.180	2.337	2.553	2.593	2.513	1.017	2.064	2.273	2.317	2.236
Homogeneity	0.00	50.260	41.620	41.720	41.720	41.600	48.060	42.770	42.800	42.800	42.780	53.120	44.380	43.840	43.840	44.160
	0.25	97.460	95.040	93.880	93.900	93.880	95.800	87.160	86.600	86.570	86.790	82.220	75.720	75.190	75.180	75.340
	0.50	97.620	96.500	96.100	96.110	96.180	98.980	97.020	96.690	96.640	96.730	97.040	93.500	93.080	93.110	93.190
	1.00	97.740	96.800	96.620	96.600	96.620	98.820	97.070	96.810	96.760	96.840	99.060	97.290	97.060	97.010	97.080
	1.50	97.810	96.930	96.740	96.720	96.790	98.820	97.350	97.140	97.090	97.170	98.980	97.490	97.280	97.240	97.310
	2.00	97.870	97.090	96.930	96.910	96.930	98.820	97.500	97.280	97.240	97.320	98.980	97.720	97.510	97.470	97.550
	2.50	97.890	97.090	96.900	96.880	96.970	98.820	97.590	97.390	97.340	97.420	98.980	97.830	97.630	97.590	97.660
	3.00	97.930	97.180	97.020	96.990	97.020	98.820	97.620	97.400	97.360	97.450	98.990	97.910	97.690	97.650	97.730
Quality index	0.00	74.794	66.306	66.465	66.464	66.292	73.985	70.926	70.949	70.949	70.935	76.411	71.597	71.240	71.240	71.457
	0.25	96.936	92.369	91.510	91.494	91.375	97.341	90.738	90.525	90.438	90.659	89.102	87.107	86.896	86.844	87.014
	0.50	97.105	93.785	93.666	93.701	93.682	98.120	94.292	94.081	94.068	94.132	98.136	93.583	93.376	93.386	93.458
	1.00	97.819	95.435	95.476	95.469	95.446	98.544	95.696	95.557	95.545	95.610	98.612	95.668	95.545	95.536	95.598
	1.50	98.269	96.375	96.421	96.429	96.437	99.040	96.836	96.733	96.720	96.795	99.074	96.842	96.745	96.734	96.806
	2.00	98.649	96.978	97.025	97.011	97.008	99.367	97.470	97.362	97.344	97.423	99.436	97.588	97.493	97.481	97.561
	2.50	98.803	97.220	97.248	97.249	97.275	99.243	97.815	97.698	97.678	97.767	99.312	98.000	97.899	97.880	97.966
	3.00	98.935	97.436	97.463	97.440	97.453	99.110	97.996	97.867	97.844	97.940	99.170	98.223	98.107	98.089	98.182

Table SI 3 : Mixing Efficiency, Standard Deviation Percentage (STD%), Homogeneity Index (HI), and Quality Index across Different ϕ and Panels over Time

		PANEL I					PANEL II					PANEL III				
	t(s)	0°	1°	2°	3°	4°	0°	1°	2°	3°	4°	0°	1°	2°	3°	4°
Mixing Eff	0.00	99.328	99.610	99.661	99.590	99.590	99.911	99.763	99.764	99.709	99.574	99.703	99.645	99.540	99.736	99.854
	0.25	96.411	97.545	97.712	96.962	96.962	98.883	94.964	94.816	94.143	93.874	95.983	93.196	92.918	92.542	92.362
	0.50	96.589	97.913	98.247	97.461	97.461	97.259	97.507	97.673	97.009	96.851	99.232	96.348	96.371	95.726	95.544
	1.00	97.898	97.414	97.846	97.210	97.210	98.268	97.013	97.445	96.829	96.752	98.163	97.086	97.448	96.839	96.732
	1.50	98.728	96.858	97.622	96.860	96.860	99.261	96.564	97.172	96.553	96.521	99.169	96.623	97.178	96.571	96.520
	2.00	99.427	97.545	97.407	96.741	96.741	99.914	94.964	96.982	96.361	96.358	99.891	96.279	96.971	96.354	96.338
	2.50	99.716	97.913	97.335	96.577	96.577	99.666	97.507	96.867	96.251	96.248	99.645	96.071	96.836	96.228	96.218
	3.00	99.940	97.414	97.184	96.562	96.562	99.401	97.013	96.768	96.160	96.175	99.349	95.942	96.736	96.137	96.135
STD %	0.00	49.403	43.705	43.744	43.702	43.720	51.835	45.688	45.689	45.696	45.706	46.963	41.883	41.889	41.877	41.873
	0.25	2.450	1.179	1.377	1.198	1.171	4.365	2.748	2.786	2.831	2.794	19.006	15.644	15.700	15.725	15.555
	0.50	2.294	1.134	1.247	1.156	1.156	1.023	0.435	0.422	0.412	0.386	3.049	2.437	2.465	2.504	2.474
	1.00	2.208	1.128	1.314	1.188	1.191	1.182	0.421	0.464	0.441	0.430	0.947	0.349	0.350	0.335	0.310
	1.50	2.163	1.081	1.216	1.128	1.141	1.186	0.402	0.455	0.433	0.418	1.023	0.319	0.354	0.341	0.321
	2.00	2.116	1.179	1.294	1.174	1.176	1.185	2.748	0.449	0.427	0.419	1.023	0.304	0.344	0.332	0.313
	2.50	2.106	1.134	1.203	1.121	1.131	1.179	0.435	0.445	0.420	0.410	1.019	0.291	0.338	0.326	0.309
	3.00	2.073	1.128	1.283	1.163	1.170	1.180	0.421	0.438	0.424	0.414	1.017	0.295	0.329	0.322	0.305
Homogeneity	0.00	50.260	56.460	56.400	56.480	56.440	48.060	54.200	54.200	54.170	54.100	53.120	57.970	57.920	58.010	58.070
	0.25	97.460	98.850	98.650	98.840	98.870	95.800	97.380	97.350	97.330	97.370	82.220	85.350	85.340	85.370	85.550
	0.50	97.620	98.890	98.770	98.870	98.870	98.980	99.580	99.590	99.600	99.630	97.040	97.650	97.620	97.600	97.630
	1.00	97.740	98.900	98.710	98.840	98.840	98.820	99.590	99.550	99.570	99.580	99.060	99.660	99.660	99.670	99.700
	1.50	97.810	98.950	98.810	98.910	98.890	98.820	99.610	99.560	99.580	99.600	98.980	99.690	99.660	99.670	99.690
	2.00	97.870	98.850	98.740	98.860	98.860	98.820	97.380	99.560	99.590	99.600	98.980	99.710	99.670	99.680	99.700
	2.50	97.890	98.890	98.830	98.920	98.910	98.820	99.580	99.570	99.600	99.610	98.980	99.720	99.670	99.690	99.700
	3.00	97.930	98.900	98.750	98.880	98.870	98.820	99.590	99.580	99.590	99.600	98.990	99.720	99.680	99.690	99.710
Quality index	0.00	74.794	78.035	78.031	78.035	78.015	73.985	76.982	76.982	76.940	76.837	76.411	78.808	78.730	78.873	78.962
	0.25	96.936	98.198	98.181	97.901	97.916	97.341	96.172	96.083	95.736	95.622	89.102	89.273	89.129	88.956	88.956
	0.50	97.105	98.402	98.509	98.166	98.166	98.120	98.543	98.632	98.304	98.240	98.136	96.999	96.996	96.663	96.587
	1.00	97.819	98.157	98.278	98.025	98.025	98.544	98.302	98.498	98.199	98.166	98.612	98.373	98.554	98.255	98.216
	1.50	98.269	97.904	98.216	97.885	97.875	99.040	98.087	98.366	98.066	98.061	99.074	98.156	98.419	98.121	98.105
	2.00	98.649	98.198	98.074	97.801	97.801	99.367	96.172	98.271	97.975	97.979	99.436	97.994	98.320	98.017	98.019
	2.50	98.803	98.402	98.083	97.749	97.744	99.243	98.543	98.219	97.926	97.929	99.312	97.895	98.253	97.959	97.959
	3.00	98.935	98.157	97.967	97.721	97.716	99.110	98.302	98.174	97.875	97.887	99.170	97.831	98.208	97.914	97.923