Chapter 5
Results and Discussions on Classification of Ocimum Seed Powder

5.1 Results

This experiment was performed on 5 series of test, i.e. U1-U5, with respected to superficial gas velocity, the first two series from which were discarded due to inconsistency because of inexperience of the researcher, so only experiment on U3, U4 and U5 (Table 4.2) were evaluated. Each series of data also consisted of 5 sets, H1-H5 (Table 4.3), corresponding to heights of the column used in test run. For comparing purpose, experimental data were present as W_i/W_{io} and X_i/X_{io} and summarized in Tables 5.1 and 5.2 respectively. To observe the classifying tendency of particles, the log-normal plot between X_i/X_{io} and time used in each run of each data set obtained from Table 5.2 were plotted (Appendix F). To observe removal trend of each particle class from system, plots of W_i/W_{io} and X_i/X_{io} versus time of each particle cut-size at various heights and superficial velocities were performed and shown in Appendix G. Comparison of the W_i/W_{io} versus time plot and the X_i/X_{io} versus time plot seem to be equivalent excepted for coarse particles that were not removed from the system . This phenomena may be attributed to the fact that as fine particles were expelled from the bed , the mass fraction of coarse particles were eventually increased whereby their weight were still unchanged.

5.1.1 Classification of ocimum seed powder

Thorough examination on classification tendency in Appendix F, collection of required particles, which is larger than 114.56 μm cut size, was most efficiently

Table 5.1a Experimental data of U3 series ; presented in value of W_i/W_{io}

freeboard height	time (min)	mesh size 20-40	40-60	60-80	80-100	100-120	120-140	140-200	200-325	325-
H1	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	0.9821	0.7920	0.0381	0.0067	0.0136	0.0172	0.0371	0.0254	0.0390
	3	1.1113	0.5780	0.0105	0.0045	0.0102	0.0107	0.0124	0.0127	0.0130
	4	0.9343	0.7376	0.0243	0.0112	0.0085	0.0107	0.0186	0.0102	0.0078
	5	0.9646	0.6412	0.0202	0.0090	0.0068	0.0129	0.0124	0.0051	0.0043
	6	1.0746	0.5800	0.0178	0.0067	0.0068	0.0086	0.0186	0.0051	0.0009
H2	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	0.9359	1.0699	0.2227	0.0224	0.0255	0.0343	0.0495	0.0381	0.0875
	3	1.0969	1.0372	0.1271	0.0045	0.0136	0.0172	0.0433	0.0203	0.0260
	4	0.9853	0.9895	0.1085	0.0112	0.0238	0.0150	0.0433	0.0178	0.0156
	5	1.0651	0.8921	0.0551	0.0090	0.0119	0.0107	0.0309	0.0102	0.0069
	6	0.9487	0.8729	0.0429	0.0045	0.0034	0.0043	0.0124	0.0025	0.0026
H3	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	1.0475	1.0429	0.1952	0.0157	0.0187	0.0150	0.0309	0.0280	0.0866
	3	1.0252	0.9973	0.1247	0.0090	0.0170	0.0150	0.0186	0.0178	0.0147
	4	1.0284	0.9781	0.1109	0.0112	0.0119	0.0150	0.0433	0.0127	0.0087
	5	1.0188	0.9107	0.0656	0.0090	0.0068	0.0086	0.0124	0.0076	0.0052
	6	0.9614	0.9408	0.0786	0.0067	0.0085	0.0064	0.0124	0.0025	0.0043
H4	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	0.9455	1.1419	0.3741	0.0291	0.0221	0.0300	0.0680	0.0432	0.0424
	3	1.0077	1.1036	0.3239	0.0202	0.0238	0.0279	0.0680	0.0305	0.0615
	4	0.9359	1.0357	0.1466	0.0045	0.0136	0.0257	0.0433	0.0229	0.0139
	5	1.0826	1.0222	0.1563	0.0045	0.0119	0.0129	0.0186	0.0051	0.0087
	6	1.0427	0.9273	0.0858	0.0090	0.0068	0.0086	0.0124	0.0025	0.0043
H5	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	0.9949	1.1015	0.3976	0.0381	0.0221	0.0279	0.0557	0.0356	0.1421
	3	1.0635	1.1155	0.4090	0.0381	0.0238	0.0279	0.0680	0.0305	0.0632
	4	1.0842	1.0859	0.3353	0.0224	0.0170	0.0129	0.0309	0.0229	0.0269
	5	1.0794	1.0590	0.2340	0.0134	0.0170	0.0215	0.0309	0.0153	0.0130
	6	0.8801	1.0481	0.1765	0.0090	0.0017	0.0086	0.0186	0.0025	0.0052

Note : value greater than 1 is the resulting error of mixing, sizing and weighing

Table 5.1b Experimental data of U4 series ; presented in value of W_i/W_{io}

freeboard height	time (min)	mesh size								
		20-40	40-60	60-80	80-100	100-120	120-140	140-200	200-325	325-
		U4								
H1	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.5134	0.5004	0.1882	0.0235	0.0095	0.0135	0.0346	0.0142	0.1310
	2	0.4911	0.5051	0.0578	0.0078	0.0048	0.0075	0.0130	0.0071	0.0655
	3	0.5112	0.5261	0.0544	0.0110	0.0072	0.0060	0.0130	0.0036	0.0097
	4	0.5625	0.5000	0.0414	0.0110	0.0060	0.0060	0.0043	0.0018	0.0067
	5	0.4743	0.4946	0.0340	0.0078	0.0072	0.0075	0.0043	0.0018	0.0030
	10	0.4955	0.5102	0.0312	0.0094	0.0048	0.0045	0.0043	0.0000	0.0000
H2	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.5335	0.4924	0.1463	0.0172	0.0143	0.0150	0.0303	0.0231	0.0794
	2	0.4967	0.5087	0.1514	0.0125	0.0083	0.0120	0.0216	0.0107	0.0388
	3	0.5603	0.4985	0.1508	0.0094	0.0060	0.0105	0.0216	0.0071	0.0164
	4	0.4877	0.5134	0.1633	0.0094	0.0072	0.0105	0.0130	0.0053	0.0085
	5	0.4989	0.5058	0.1786	0.0094	0.0060	0.0060	0.0043	0.0036	0.0049
	10	0.4732	0.5033	0.1672	0.0063	0.0048	0.0075	0.0087	0.0018	0.0000
H3	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.4810	0.5160	0.3560	0.2649	0.0989	0.0420	0.0563	0.0569	0.1613
	2	0.5123	0.4946	0.1627	0.0078	0.0072	0.0105	0.0260	0.0196	0.0437
	3	0.5000	0.5160	0.1565	0.0094	0.0072	0.0090	0.0216	0.0142	0.0158
	4	0.5301	0.4851	0.1667	0.0094	0.0060	0.0075	0.0173	0.0071	0.0109
	5	0.5000	0.4978	0.1774	0.0078	0.0048	0.0060	0.0087	0.0053	0.0049
	10	0.4978	0.4931	0.1519	0.0078	0.0060	0.0060	0.0043	0.0018	0.0000
H4	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.4955	0.5181	0.3957	0.3339	0.1931	0.0916	0.1039	0.0498	0.1947
	2	0.5603	0.4840	0.1570	0.0110	0.0083	0.0090	0.0303	0.0125	0.0455
	3	0.5190	0.5004	0.1616	0.0094	0.0119	0.0090	0.0173	0.0107	0.0127
	4	0.5547	0.5098	0.1474	0.0094	0.0048	0.0045	0.0130	0.0071	0.0115
	5	0.5469	0.5015	0.1400	0.0063	0.0036	0.0060	0.0043	0.0036	0.0024
	10	0.4743	0.5025	0.1525	0.0078	0.0048	0.0030	0.0043	0.0018	0.0000
H5	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.5000	0.4960	0.4008	0.3088	0.1156	0.0450	0.0563	0.0534	0.1710
	2	0.5446	0.4924	0.1922	0.0141	0.0155	0.0075	0.0216	0.0178	0.0297
	3	0.5391	0.5131	0.1865	0.0110	0.0131	0.0105	0.0130	0.0125	0.0218
	4	0.5268	0.5120	0.1536	0.0094	0.0095	0.0060	0.0130	0.0053	0.0121
	5	0.4944	0.4975	0.1667	0.0125	0.0107	0.0045	0.0043	0.0036	0.0036
	10	0.4866	0.4960	0.1769	0.0063	0.0083	0.0060	0.0043	0.0036	0.0000

Note : value greater than 1 is the resulting error of mixing, sizing and weighing

Table 5.1c Experimental data of U5 series ; presented in value of W_i/W_{io}

freeboard height	time (min)	mesh size 20-40	40-60	60-80	80-100	100-120	120-140	140-200	200-325	325-
H1	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.9384	1.0145	1.0291	0.8968	0.6988	0.0300	0.7788	0.0995	0.7486
	2	0.9117	1.0348	0.9281	0.7473	0.2317	0.0601	0.2019	0.0853	0.6752
	3	0.9280	1.0046	0.9633	0.2918	0.1931	0.0450	0.1635	0.0521	0.5484
	4	1.0572	1.0447	0.9052	0.1779	0.1004	0.0360	0.1154	0.0237	0.4383
	5	1.0423	0.9872	0.9878	0.2135	0.1236	0.0330	0.0865	0.0332	0.3804
H2	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.9206	1.0174	0.9969	0.8541	0.8147	0.4835	0.6442	0.6161	0.8009
	2	1.0290	1.0476	0.9939	0.6797	0.2201	0.1261	0.2308	0.2844	0.7164
	3	0.9265	1.0087	1.0321	0.6655	0.1931	0.0661	0.1346	0.2038	0.5250
	4	1.0958	0.9710	0.9235	0.4484	0.1274	0.0541	0.0769	0.1611	0.4238
	5	0.9993	0.9762	1.0413	0.4733	0.1236	0.0240	0.0673	0.1374	0.3882
H3	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.8790	1.0580	1.0275	0.9644	1.0039	0.8468	0.4904	0.4502	0.8587
	2	0.9903	1.0017	1.0413	0.8363	0.3514	0.1502	0.1442	0.2938	0.6841
	3	1.0616	0.9182	0.9740	0.5836	0.2124	0.0541	0.1250	0.2512	0.5873
	4	1.0260	0.9861	1.0092	0.4520	0.1042	0.0931	0.1058	0.1517	0.5050
	5	1.0557	1.0366	0.9067	0.4306	0.1120	0.0300	0.0577	0.1043	0.3582
H4	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.9681	1.0331	0.9725	1.0783	0.9807	0.8108	0.5096	0.4171	0.7575
	2	1.0572	1.0133	0.9878	0.6940	0.3552	0.0781	0.2115	0.3033	0.6363
	3	0.9562	1.0470	0.9098	0.5445	0.2394	0.0661	0.0865	0.2370	0.6007
	4	1.0468	0.9553	1.0367	0.4804	0.1544	0.0781	0.1058	0.1232	0.4561
	5	0.9517	0.9907	1.0199	0.4626	0.1274	0.0270	0.0769	0.1090	0.3793
H5	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.0765	1.0470	0.8899	0.9964	0.6178	0.9309	0.5962	0.6682	0.8242
	2	1.0097	1.0331	1.0107	0.9253	0.6564	0.1231	0.1731	0.3412	0.6452
	3	1.0720	1.0302	0.9801	0.7260	0.5869	0.1021	0.1635	0.2275	0.4917
	4	0.9993	1.0058	1.0138	0.5053	0.4826	0.0811	0.1923	0.1659	0.4338
	5	0.8864	1.0012	1.0015	0.5836	0.5058	0.0240	0.0577	0.1374	0.3459

Note : value greater than 1 is the resulting error of mixing, sizing and weighing

Table 5.2a Experimental data of U3 series ; presented in value of X_i/X_{io}

freeboard height	time (min)	mesh size								
		20-40	40-60	60-80	80-100	100-120	120-140	140-200	200-325	325-
H1	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	3.0273	2.4413	0.1173	0.0207	0.0420	0.0529	0.1144	0.0784	0.1202
	3	4.1823	2.1751	0.0396	0.0169	0.0384	0.0404	0.0465	0.0478	0.0489
	4	3.1595	2.4943	0.0822	0.0379	0.0288	0.0363	0.0627	0.0344	0.0264
	5	3.5726	2.3748	0.0750	0.0332	0.0252	0.0477	0.0458	0.0188	0.0160
	6	4.1061	2.2163	0.0681	0.0257	0.0260	0.0328	0.0709	0.0194	0.0033
H2	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	2.1195	2.4229	0.5044	0.0507	0.0578	0.0777	0.1120	0.0863	0.1982
	3	2.6396	2.4959	0.3060	0.0108	0.0328	0.0413	0.1042	0.0489	0.0625
	4	2.5367	2.5475	0.2794	0.0288	0.0614	0.0387	0.1114	0.0458	0.0401
	5	2.9941	2.5079	0.1548	0.0252	0.0335	0.0302	0.0869	0.0286	0.0195
	6	2.8330	2.6068	0.1282	0.0134	0.0102	0.0128	0.0369	0.0076	0.0078
H3	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	2.4033	2.3928	0.4478	0.0360	0.0430	0.0344	0.0709	0.0642	0.1988
	3	2.5917	2.5212	0.3153	0.0226	0.0430	0.0380	0.0469	0.0450	0.0372
	4	2.6563	2.5265	0.2866	0.0289	0.0308	0.0388	0.1118	0.0328	0.0224
	5	2.8527	2.5501	0.1837	0.0251	0.0191	0.0240	0.0346	0.0214	0.0146
	6	2.6558	2.5989	0.2170	0.0186	0.0235	0.0178	0.0342	0.0070	0.0120
H4	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	1.9610	2.3684	0.7760	0.0604	0.0459	0.0623	0.1411	0.0896	0.0880
	3	2.1433	2.3473	0.6890	0.0429	0.0507	0.0593	0.1447	0.0649	0.1308
	4	2.3232	2.5708	0.3639	0.0111	0.0338	0.0639	0.1075	0.0568	0.0344
	5	2.6368	2.4897	0.3807	0.0109	0.0290	0.0313	0.0452	0.0124	0.0211
	6	2.8412	2.5268	0.2339	0.0244	0.0186	0.0234	0.0337	0.0069	0.0118
H5	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	2	2.0070	2.2220	0.8021	0.0768	0.0447	0.0563	0.1123	0.0718	0.2866
	3	2.1484	2.2535	0.8262	0.0769	0.0482	0.0563	0.1374	0.0616	0.1278
	4	2.3280	2.3318	0.7199	0.0481	0.0366	0.0276	0.0664	0.0491	0.0577
	5	2.4692	2.4225	0.5354	0.0307	0.0390	0.0491	0.0707	0.0349	0.0297
	6	2.1924	2.6109	0.4398	0.0223	0.0042	0.0214	0.0462	0.0063	0.0129

Table 5.2b Experimental data of U4 series ; presented in value of Xi/Xio

freeboard height	time (min)	mesh size								
		20-40	40-60	60-80	80-100	100-120	120-140	140-200	200-325	325-
H1	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	2.1094	2.0541	0.7715	0.0987	0.0393	0.0556	0.1429	0.0587	0.5391
	2	2.3795	2.4492	0.2789	0.0361	0.0238	0.0345	0.0563	0.0356	0.3190
	3	2.5045	2.5755	0.2676	0.0517	0.0358	0.0300	0.0563	0.0178	0.0485
	4	2.8337	2.5174	0.2092	0.0580	0.0322	0.0300	0.0303	0.0125	0.0346
	5	2.5313	2.6426	0.1825	0.0423	0.0393	0.0405	0.0303	0.0125	0.0164
	10	2.5826	2.6586	0.1621	0.0470	0.0238	0.0255	0.0303	0.0018	0.0006
H2	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	2.3426	2.1622	0.6423	0.0784	0.0632	0.0646	0.1299	0.1014	0.3493
	2	2.2444	2.2990	0.6842	0.0580	0.0393	0.0556	0.0996	0.0480	0.1753
	3	2.5525	2.2703	0.6859	0.0423	0.0274	0.0495	0.0996	0.0302	0.0746
	4	2.2388	2.3563	0.7506	0.0423	0.0322	0.0495	0.0563	0.0231	0.0382
	5	2.2846	2.3179	0.8192	0.0423	0.0274	0.0300	0.0130	0.0178	0.0224
	10	2.2288	2.3716	0.7885	0.0313	0.0238	0.0345	0.0433	0.0053	0.0006
H3	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.5658	1.6800	1.1582	0.8621	0.3218	0.1351	0.1861	0.1833	0.5258
	2	2.3114	2.2315	0.7330	0.0361	0.0322	0.0495	0.1169	0.0890	0.1977
	3	2.2690	2.3418	0.7109	0.0423	0.0322	0.0405	0.0996	0.0658	0.0728
	4	2.4688	2.2580	0.7761	0.0423	0.0274	0.0345	0.0866	0.0356	0.0503
	5	2.3158	2.3048	0.8214	0.0361	0.0238	0.0300	0.0433	0.0231	0.0224
	10	2.3850	2.3610	0.7273	0.0361	0.0274	0.0300	0.0130	0.0053	0.0006
H4	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.4665	1.5337	1.1706	0.9906	0.5709	0.2703	0.3030	0.1477	0.5767
	2	2.5223	2.1803	0.7058	0.0470	0.0358	0.0405	0.1299	0.0534	0.2062
	3	2.3772	2.2939	0.7398	0.0423	0.0560	0.0405	0.0866	0.0480	0.0588
	4	2.5201	2.3179	0.6695	0.0423	0.0203	0.0195	0.0563	0.0302	0.0522
	5	2.5603	2.3451	0.6559	0.0313	0.0155	0.0300	0.0130	0.0178	0.0121
	10	2.2690	2.4031	0.7279	0.0361	0.0238	0.0150	0.0130	0.0053	0.0006
H5	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.5781	1.5649	1.2642	0.9749	0.3647	0.1396	0.1732	0.1655	0.5391
	2	2.3951	2.1636	0.8435	0.0627	0.0679	0.0345	0.0996	0.0765	0.1310
	3	2.3471	2.2351	0.8112	0.0470	0.0560	0.0450	0.0563	0.0534	0.0946
	4	2.3973	2.3295	0.7001	0.0423	0.0441	0.0255	0.0563	0.0231	0.0546
	5	2.3136	2.3280	0.7812	0.0580	0.0513	0.0195	0.0130	0.0178	0.0164
	10	2.2824	2.3244	0.8288	0.0313	0.0393	0.0300	0.0130	0.0178	0.0006

Table 5.2c Experimental data of U5 series ; presented in value of Xi/Xio

freeboard height	time (min)	mesh size								
		20-40	40-60	60-80	80-100	100-120	120-140	140-200	200-325	325-
H1	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.1272	1.2183	1.2361	1.0785	0.8399	0.0354	0.9310	0.1188	0.8990
	2	1.1858	1.3478	1.2086	0.9708	0.3024	0.0769	0.2611	0.1116	0.8791
	3	1.3039	1.4113	1.3529	0.4069	0.2708	0.0615	0.2315	0.0713	0.7695
	4	1.5042	1.4881	1.2878	0.2555	0.1443	0.0508	0.1626	0.0309	0.6235
	5	1.5232	1.4440	1.4431	0.3102	0.1779	0.0462	0.1330	0.0475	0.5562
H2	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.0373	1.1462	1.1231	0.9599	0.9150	0.5431	0.7241	0.6793	0.9025
	2	1.2666	1.2909	1.2235	0.8376	0.2688	0.1538	0.2808	0.3397	0.8825
	3	1.2422	1.3538	1.3835	0.8923	0.2569	0.0877	0.1823	0.2684	0.7045
	4	1.5560	1.3782	1.3090	0.6387	0.1779	0.0769	0.1133	0.2209	0.6007
	5	1.4257	1.3934	1.4871	0.6734	0.1779	0.0354	0.0985	0.1900	0.5539
H3	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	0.9360	1.1266	1.0941	1.0274	1.0652	0.9015	0.5271	0.4656	0.9139
	2	1.2270	1.2412	1.2894	1.0365	0.4328	0.1846	0.1823	0.3539	0.8471
	3	1.4463	1.2519	1.3271	0.7956	0.2905	0.0723	0.1626	0.3325	0.7998
	4	1.4105	1.3553	1.3875	0.6186	0.1443	0.1277	0.1478	0.2043	0.6942
	5	1.5057	1.4777	1.2918	0.6131	0.1581	0.0415	0.0837	0.1425	0.5106
H4	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.0518	1.1239	1.0573	1.1715	1.0652	0.8800	0.5567	0.4418	0.8237
	2	1.3321	1.2761	1.2439	0.8741	0.4466	0.0969	0.2611	0.3705	0.8003
	3	1.2643	1.3848	1.2024	0.7172	0.3162	0.0877	0.1133	0.3088	0.7946
	4	1.4608	1.3329	1.4471	0.6679	0.2174	0.1077	0.1478	0.1663	0.6366
	5	1.3709	1.4279	1.4698	0.6679	0.1838	0.0415	0.1133	0.1496	0.5465
H5	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	1	1.1485	1.1182	0.9506	1.0639	0.6581	0.9938	0.6404	0.6960	0.8791
	2	1.2155	1.2433	1.2149	1.1131	0.7905	0.1492	0.2118	0.4038	0.7758
	3	1.3625	1.3103	1.2471	0.9215	0.7431	0.1277	0.2118	0.2850	0.6241
	4	1.3450	1.3553	1.3647	0.6807	0.6502	0.1077	0.2611	0.2209	0.5847
	5	1.2536	1.4163	1.4165	0.8248	0.7154	0.0354	0.0837	0.1900	0.4894

operated at the gas velocity of 1.15 m/s and freeboard high of 1.5 m (U5 and H5). At this condition, though some particles of 136.47-163.77 μm group were elutriated (Appendix G3.2 and G3.3), the separating efficiency was about 90%, based on the total original weight of particles in 136.47-601.04 μm class size. Approximately 40 % of fine was removed with the product yield of 0.3 kg. Estimation of classifying efficacy and yield of product are shown in Appendix H.

5.1.2 Elutriation of ocimum seed powder

In order to figure out the type of relation of X_i/X_{io} and time in this system, Least-square curve fitting method was applied. Graphs of Figures in Appendix F and G showed that the type of correlation appears to be in the form of

$$\frac{X_i}{X_{io}} = A + Be^{\beta t} \qquad 5.1$$

where A and B are constants, ß is the elutriation velocity constant which is equivalent to k in Leva's equation. When value of A approach zero, log-normal plot of X_i/X_{io} versus time will be a straight line. Value of these constants obtained from regression analysis are shown in Table 5.3, and Figure 5.1 are graphs calculated from Table 5.3. All curves of particle smaller than 44 μm are linear, while most of the others conform to the equation 5.1 as evidenced by the correlation of determination (r^2).

Unfortunately deviations from equation 5.1 were unexpected detected as the column height as well as particle size were increased with a decrease in superficial velocity, for example, as seen in Appendix G2.1, G2.2 etc. This so-called "lag-phase" phenomena caused a delay in particle removal at small time such as 1 minute, and when these phenomena occurred, regression was done at the point where X_i/X_{io} started decline. It is noted that in series of U3, initial data at time of 1 minute was not collected to avoid start-up phenomena. However, after

Table 5.3 Value of constants and coefficients of determination obtained from regression analysis

gas velocity	U-3					U-4					U-5				
freeboard height	H1	H2	H3	H4	H5	H1	H2	H3	H4	H5	H1	H2	H3	H4	H5
60-80 mesh															
A =	0.066	0.014	0.168												
B =	0.934	0.986	0.832												
k =	-1.551	-0.367	-0.553												
r^2 =	0.998	0.994	0.994												
note :				!	!	!	!	!	!	!	!	!	!	!	!
80-100 mesh															
A =	0.029	0.019	0.023	0.018	0.039	0.047	0.046	0.041	0.039	0.049					
B =	0.971	0.981	0.977	0.982	0.961	0.953	0.954	34.676	106.972	63.224					
k =	-2.937	-1.754	-2.189	-1.532	-1.505	-2.937	-3.352	-2.996	-4.722	-4.224					
r^2 =	1.000	1.000	1.000	0.999	0.998	1.000	1.000	1.000	1.000	1.000					
note :								5 pt.	5 pt.	5 pt.	!	!	!	!	!
100-120 mesh															
A =	0.029	0.033	0.028	0.031	0.030	0.033	0.031	0.028	0.030	0.050	0.033	0.028	0.028	0.030	
B =	0.971	0.967	0.972	0.969	0.970	0.967	0.969	18.902	49.280	5.335	0.967	0.125	18.902	49.280	
k =	-2.096	-1.826	-1.995	-1.995	-2.010	-4.962	-3.411	-4.163	-4.513	-2.830	-4.962	-1.263	-4.163	-4.513	
r^2 =	1.000	0.998	1.000	0.999	0.999	1.000	1.000	0.999	0.996	0.999	1.000	0.971	0.999	0.996	
note :								5 pt.	5 pt.	5 pt.		5 pt.	5 pt.	5 pt.	!
120-140 mesh															
A =	0.039	0.026	0.029	0.042	0.037	0.034	0.046	0.036	0.015	0.028	0.059	**0.000**	0.033	0.030	0.029
B =	0.961	0.974	0.971	0.958	0.963	0.966	0.954	0.964	0.985	0.972	0.941	0.859	0.588	4.829	1.675
k =	-2.112	-1.452	-2.513	-1.845	-1.871	-3.772	-3.912	-2.263	-1.419	-2.172	-3.730	-0.661	-1.755	-2.999	-2.720
r^2 =	1.000	1.000	1.000	0.999	0.999	1.000	1.000	1.000	0.998	1.000	0.999	0.953	0.996	0.995	0.965
note :												linear	5 pt.	5 pt.	5 pt.

! = failed from regression analysis

Table 5.3 Value of constants and coefficients of determination obtained from regression analysis (continue)

gas velocity	U-3					U-4					U-5				
freeboard height	H1	H2	H3	H4	H5	H1	H2	H3	H4	H5	H1	H2	H3	H4	H5
140-200 mesh															
A =	0.054	0.081	0.057	0.064	0.071	0.040	0.065	0.082	0.044	0.049	0.033	0.000	0.072	0.062	0.087
B =	0.946	0.919	0.943	0.936	0.929	0.960	0.935	0.918	0.956	0.951	0.402	0.915	0.928	0.938	0.913
k =	-1.435	-1.585	-2.112	-1.091	-1.370	-2.216	-2.590	-2.112	-1.259	-1.959	-1.308	-0.490	-0.842	-0.751	-0.701
r^2 =	0.999	0.996	0.994	0.992	0.995	0.999	0.993	0.997	0.998	0.997	0.964	0.926	0.987	0.990	0.948
note :											**5 pt.**	**5 pt.**			
200-325 mesh															
A =	0.025	0.026	0.022	0.026	0.033	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
B =	0.975	0.974	0.978	0.974	0.967	0.078	0.127	0.281	0.194	0.267	0.172	0.490	0.821	0.809	0.918
k =	-1.415	-1.359	-1.519	-1.284	-1.523	-0.415	-0.421	-0.506	-0.480	-0.566	-0.312	-0.194	-0.351	-0.360	-0.346
r^2 =	1.000	0.999	0.999	0.998	0.998	0.914	0.944	0.987	0.936	0.976	0.742	0.990	0.944	0.936	0.967
note :						**5 pt. lin**	**5 pt. lin**	**5 pt. lin**	**5 pt. lin**	**5 pt. lin**	**5 pt. lin**	**4 pt lin**	**linear**	**linear**	**linear**
325- mesh															
A =	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
B =	0.866	0.924	0.739	0.728	1.096	1.159	0.832	0.985	1.134	0.978	1.039	1.035	1.052	0.988	0.964
k =	-0.888	-0.796	-0.777	-0.711	-0.729	-0.877	-0.757	-0.772	-0.872	-0.793	-0.119	-0.126	-0.121	-0.109	-0.126
r^2 =	0.980	0.992	0.932	0.935	0.998	0.960	0.990	0.988	0.973	0.972	0.952	0.960	0.895	0.913	0.761
note :															

! = failed from regression analysis

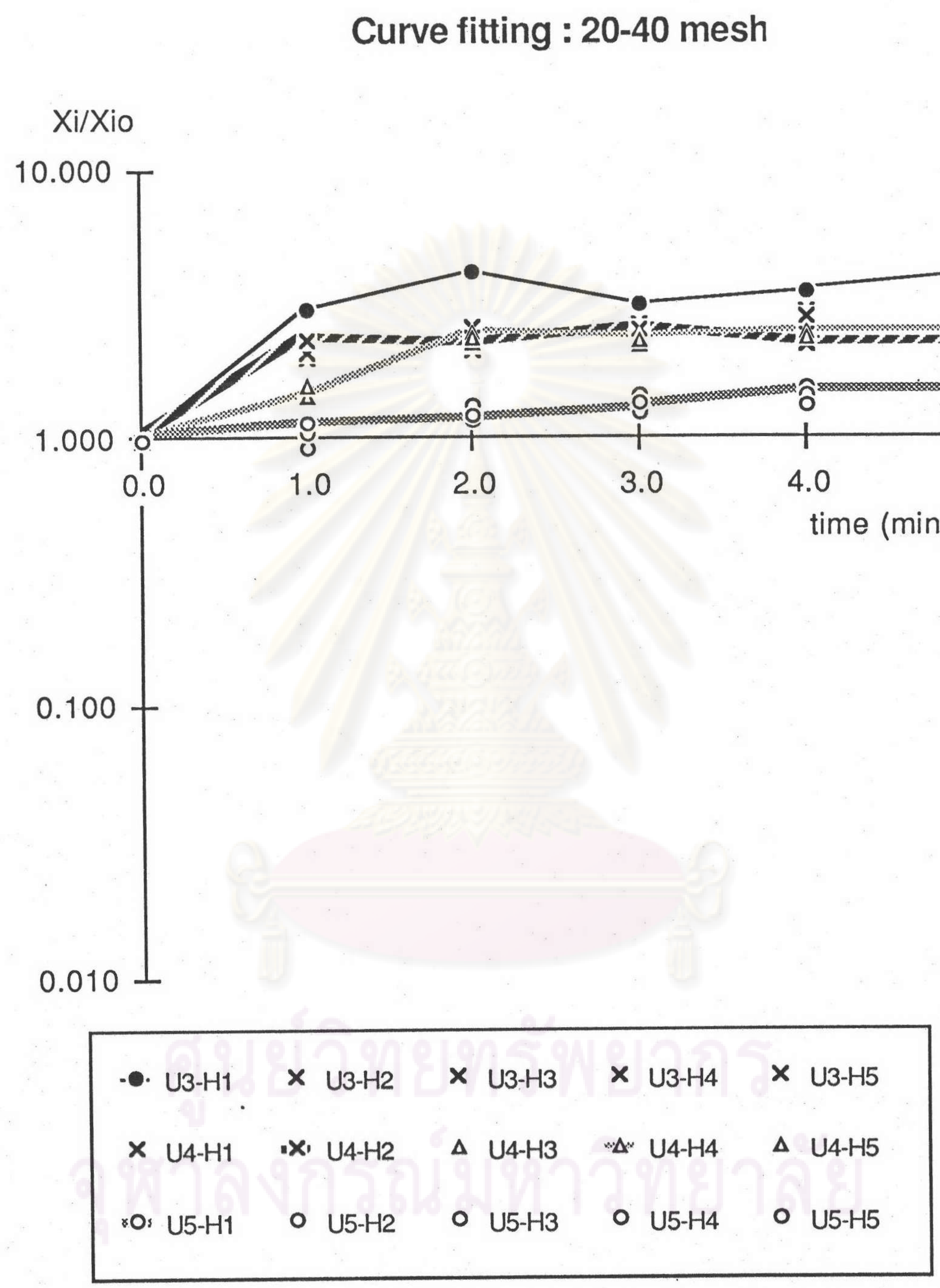


Figure 5.1a Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 20-40 mesh

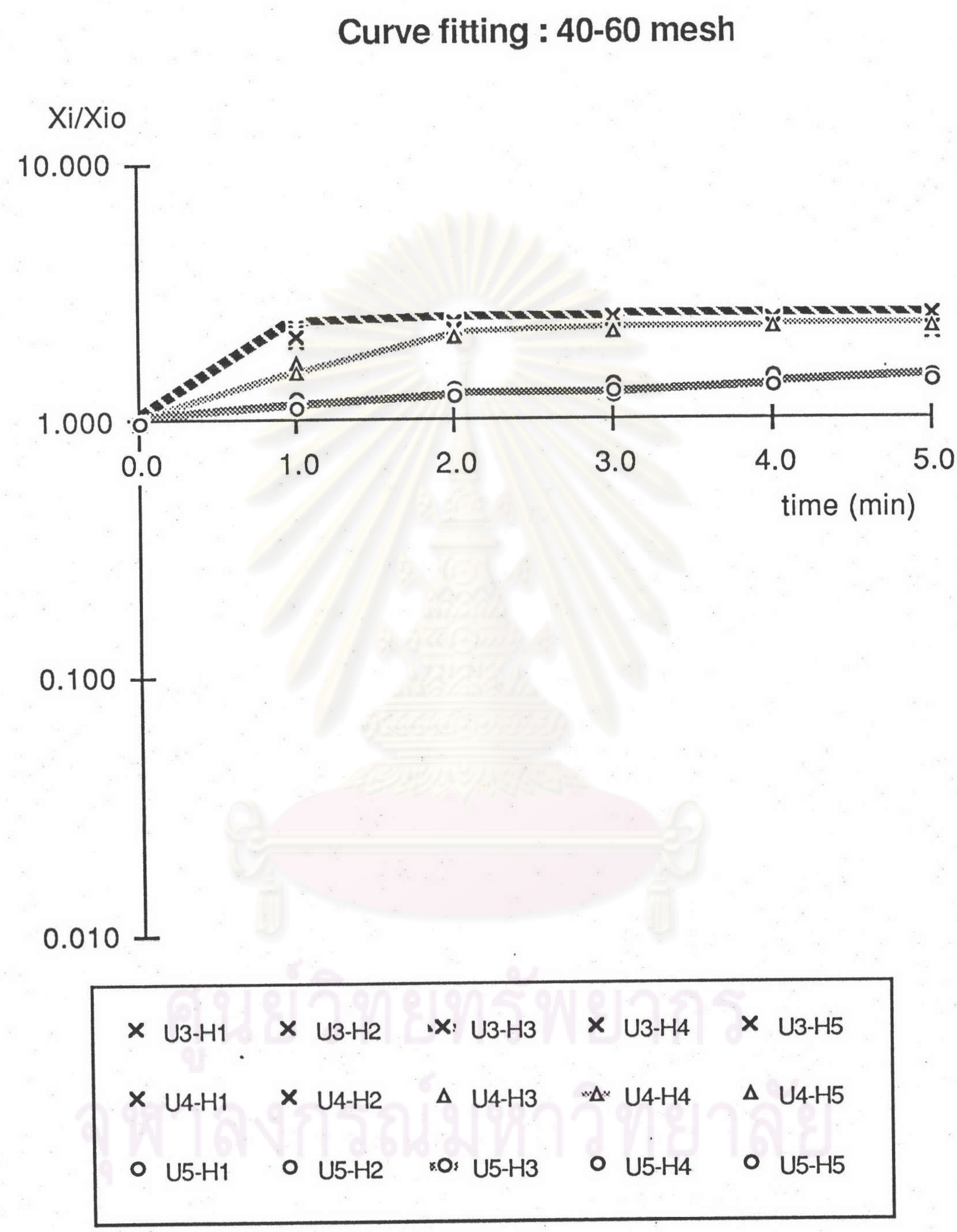


Figure 5.1b Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 40-60 mesh

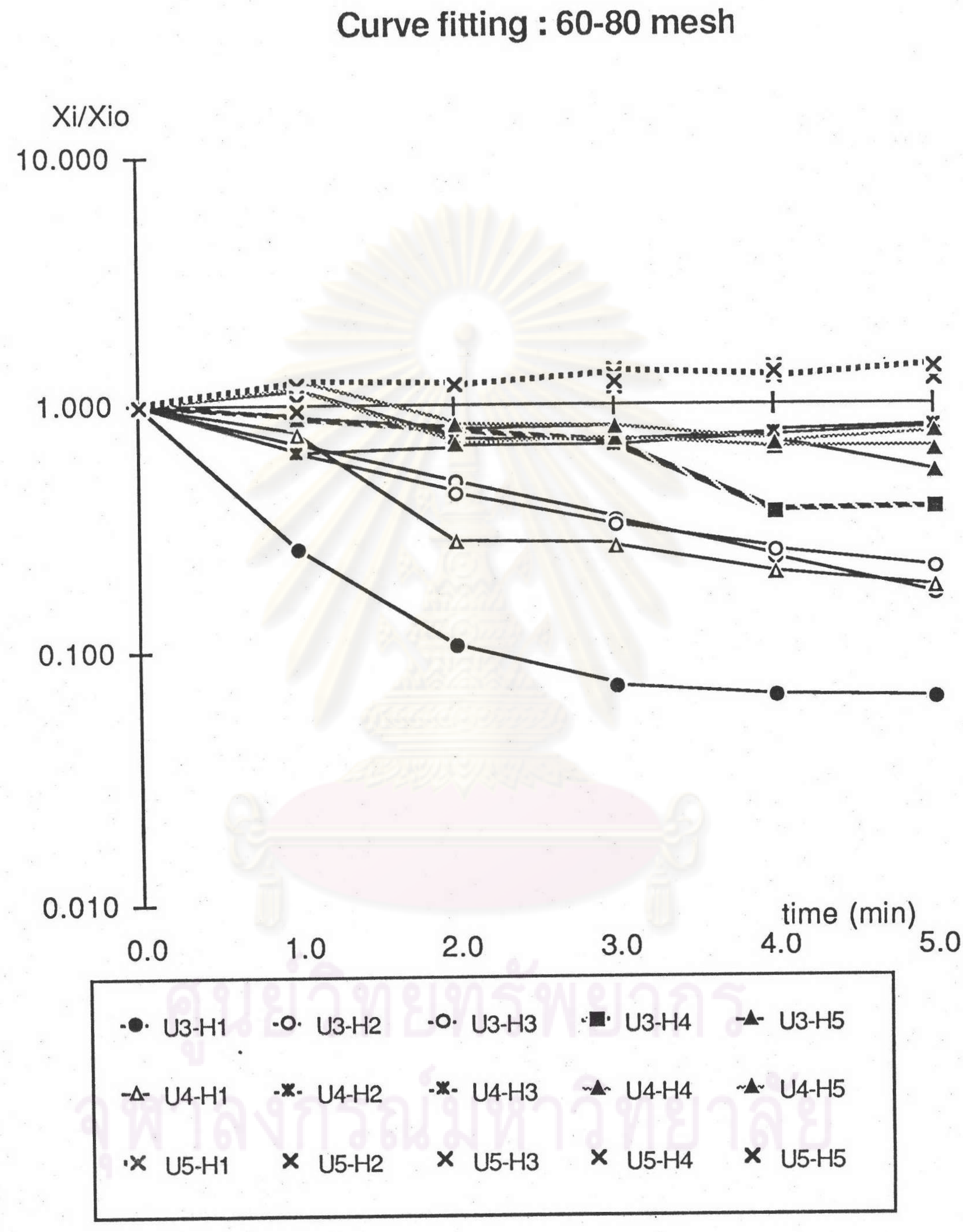


Figure 5.1c Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 60-80 mesh

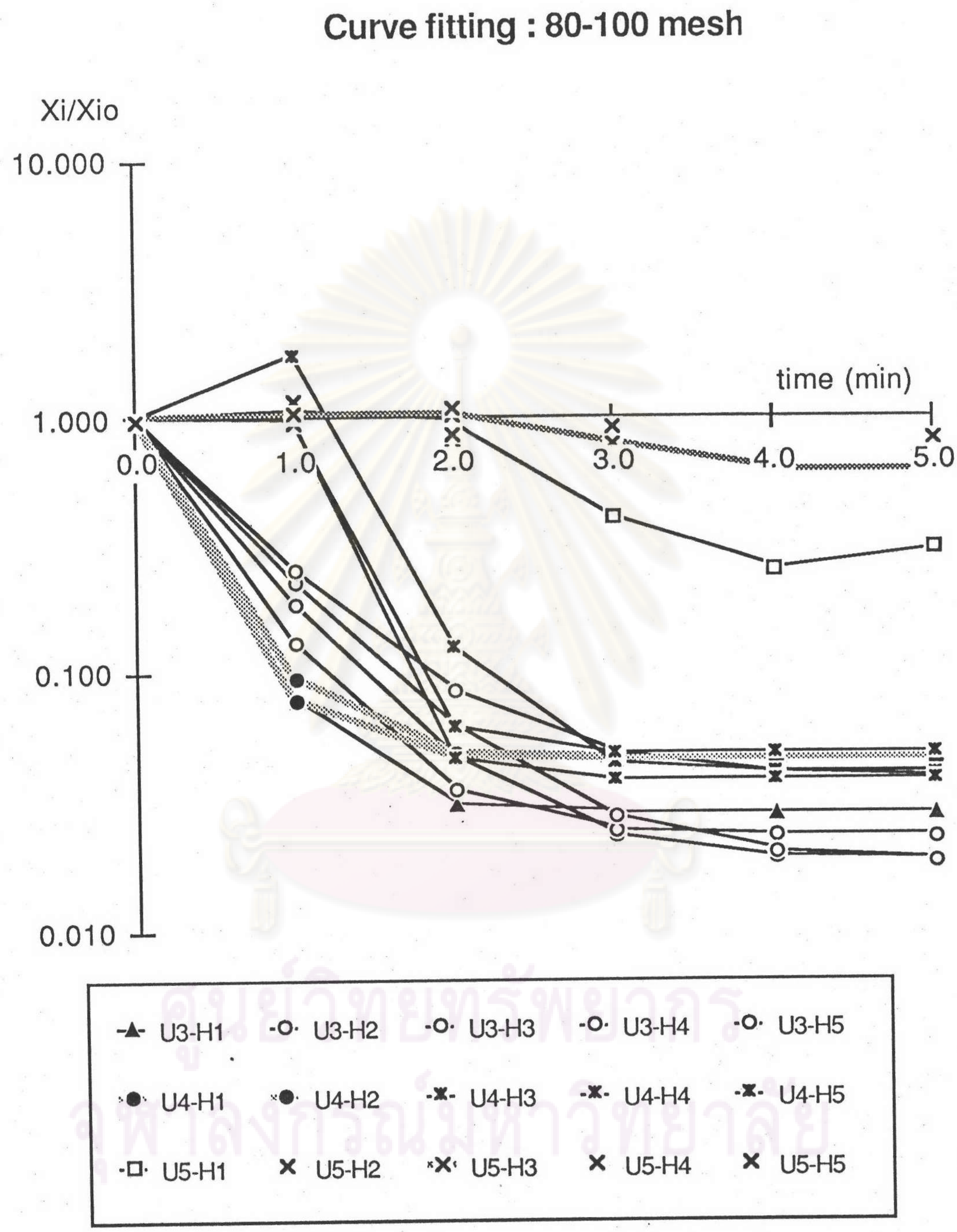


Figure 5.1d Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 80-100 mesh

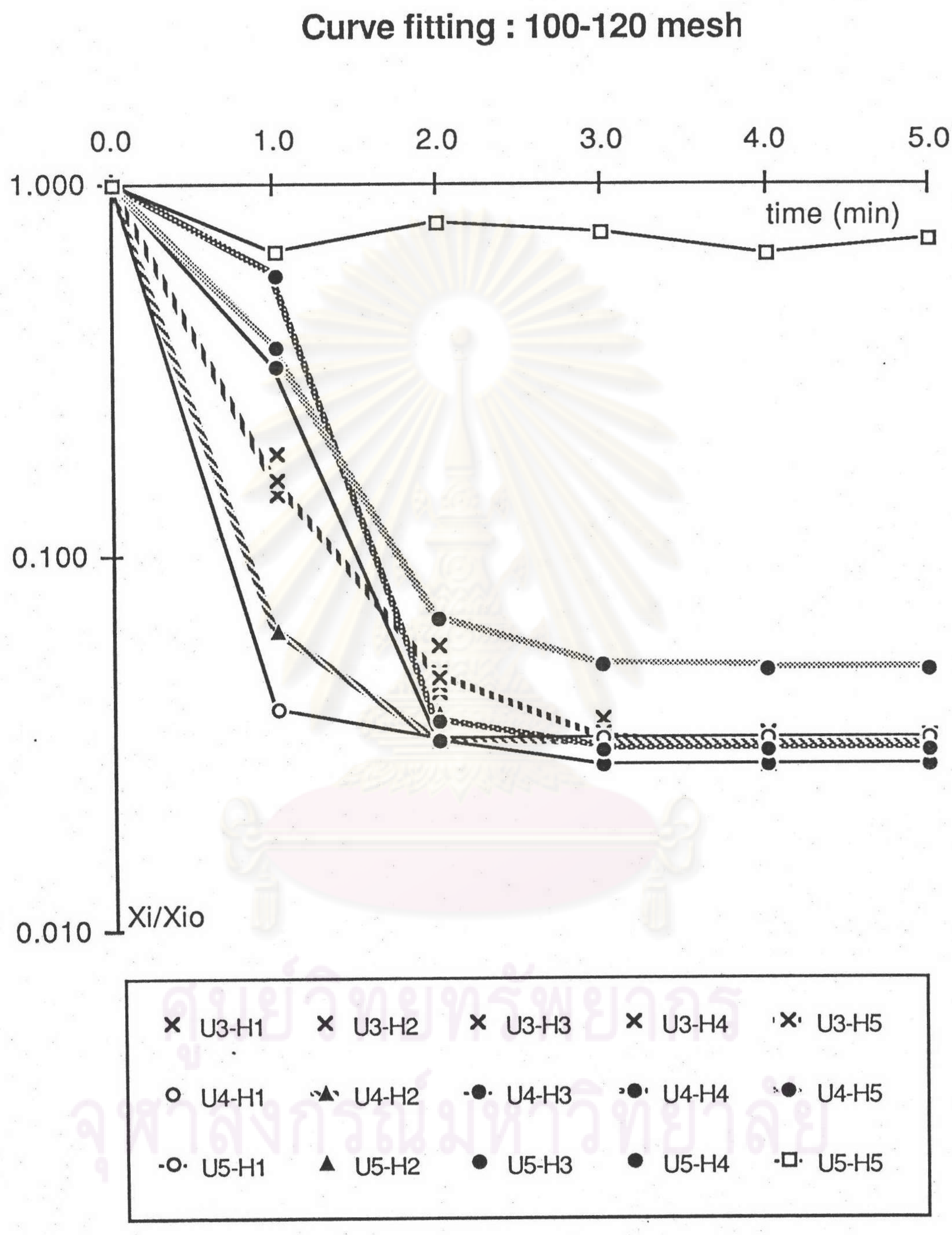


Figure 5.1e Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 100-120 mesh

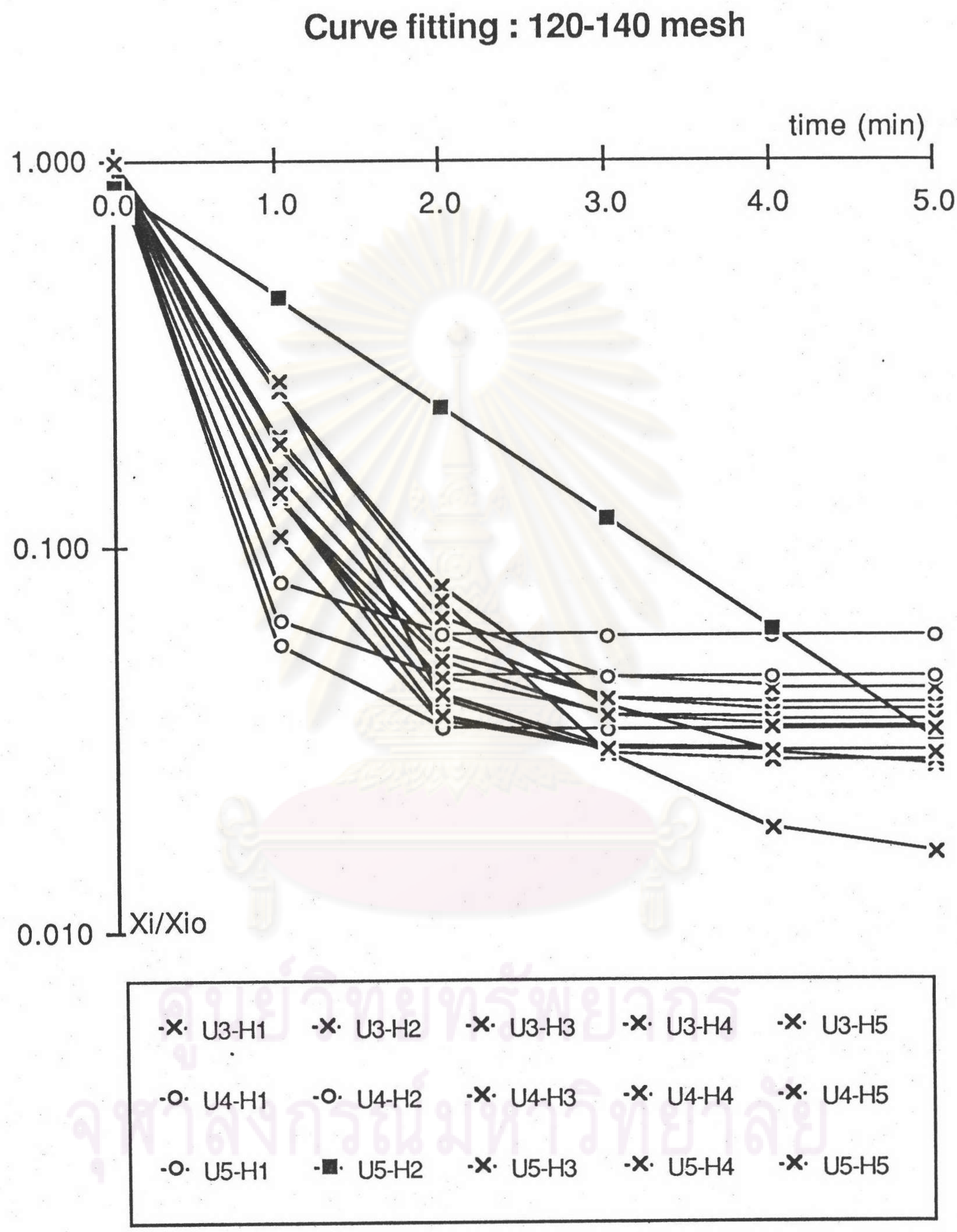


Figure 5.1f Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 120-140 mesh

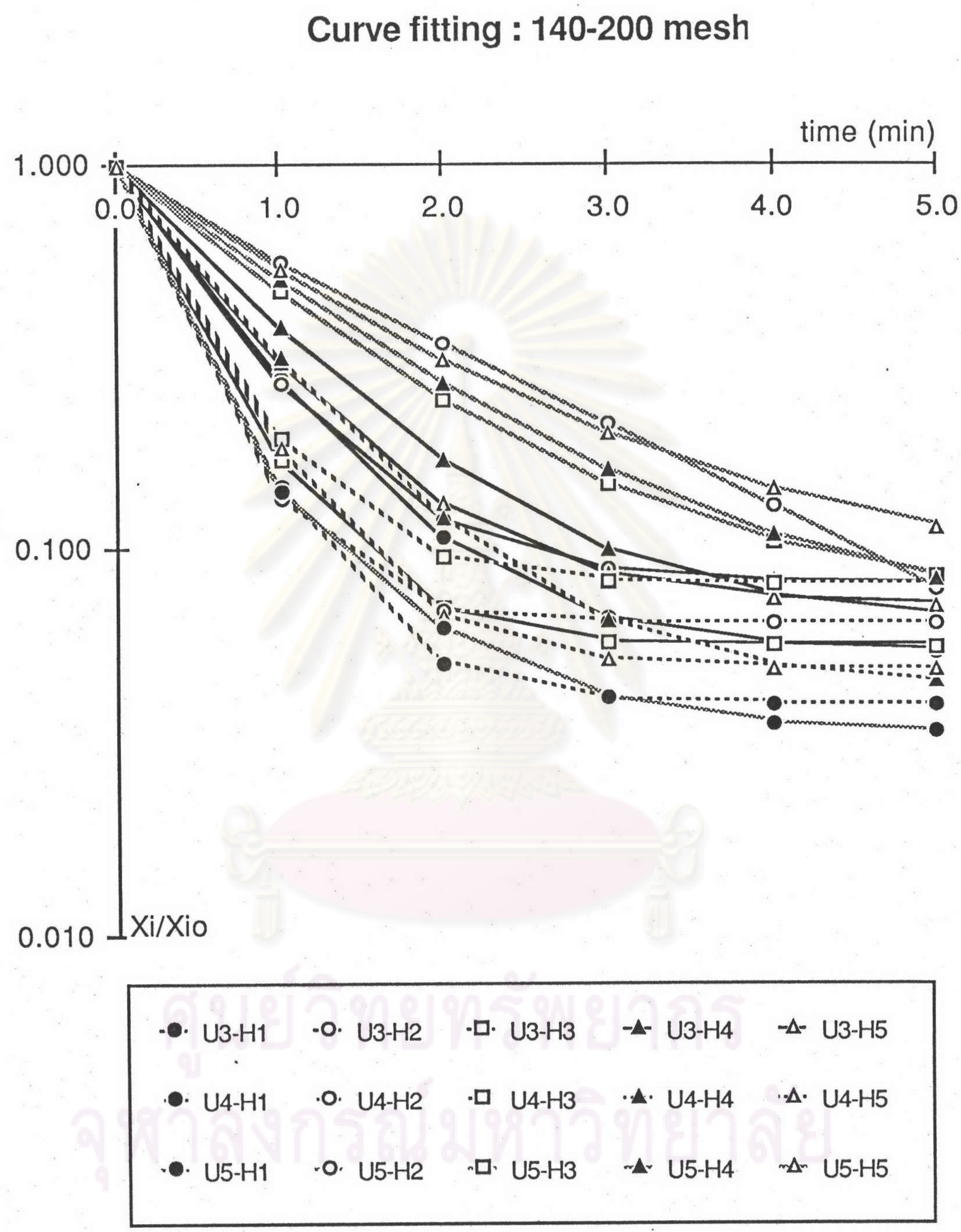


Figure 5.1g Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 140-200 mesh

Curve fitting : 200-325 mesh

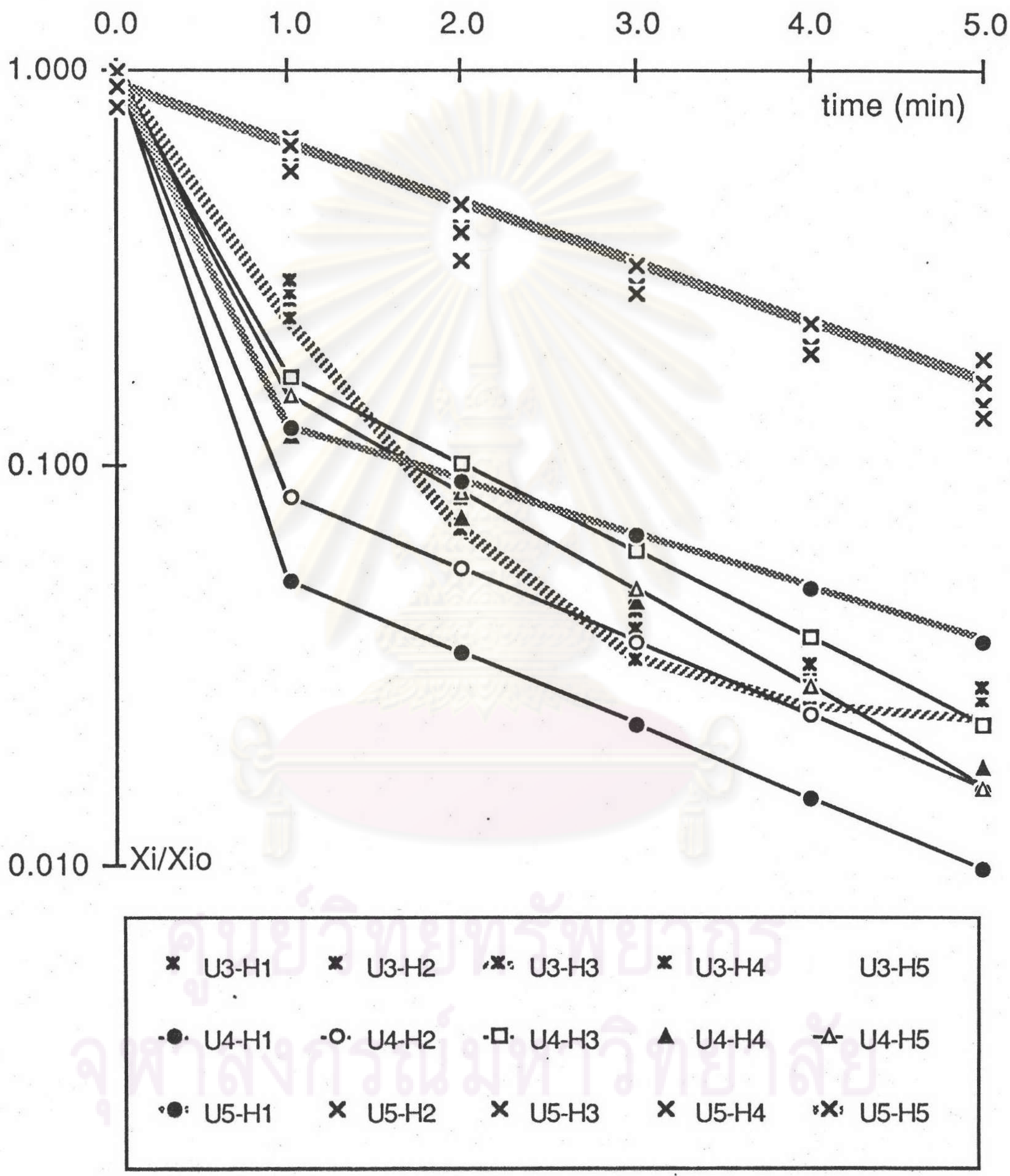


Figure 5.1h Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 200-325 mesh

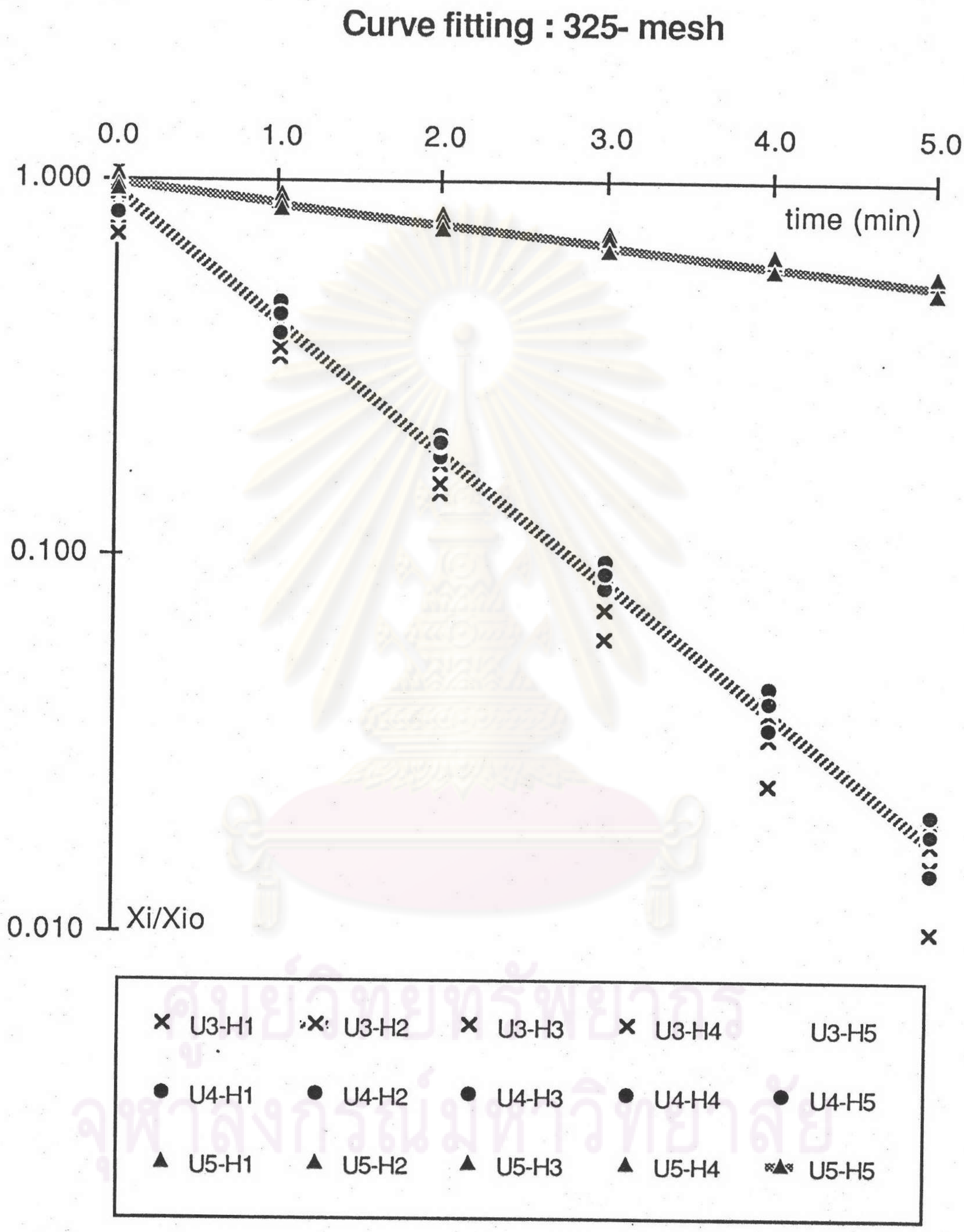


Figure 5.1i Effects of height of fluidized bed column and superficial gas velocity on elutriation rate of particle class 325- mesh

first investigation of U3 series was performed, question was arisen on this lag-phase tendency of 212.13 μm cut size at H4 and H5 (Appendix F1.4 and F1.5) which lead to the collection of data at 1 minute time on later experiment. Due to the above reasons, direct comparison of equation constants could not be done, except for particle of smallest size which follow first order rate correlation.

It can be seen from Appendix G2 through G3 that as gas velocity decreased and column height increased the lag-phase phenomena are more pronounced with the intermediate particle size groups. That is, for series of velocity U5 the lag-phase phenomena occurred with 114.45 μm fractions or larger cut size whereas series of U4 phenomena occurred with particles 136.47 μm or larger cut size. Based on these behaviors at both level of velocity, it may probably conclude that the lag-phase phenomena were absent for particles driven at velocity U3.

The constant ß in equation 5.1 seems to be function of particle size, superficial gas velocity and height of bed column. If the phenomena of 88.15 μm particle group (Figure 5.1g) was taken to be the basis while considering behaviors of other groups of particle, one could conclude as follows:

for large particles (>88.15 μm)

- there was an initial sudden loss of particles from the system in an optimal height and particle remained constant thereafter, which may be due to combined effects of particles size, gas velocity and height of column. In this range, the velocities used were high, particles size and height of column were small.

- as the gas velocity was reduced and column height as well as particle size were increased, particle loss process reflected a significant change in which the lag-phase phenomena appeared for the first minute of fluidization, after that plateau was reached the combined effect was further developed. However as the plateau level was changed and finally no particle loss from column.

for small particles (<88.15 μm)

- combined effect resulted in the opposite direction to the previous events appeared at low column height. The obtained linear relationship for smallest size group of particles as seen in Appendix G1.7, G2.7 and G3.7 suggest that the value of constant A approach zero.

- abnormal behavior, however was surprisingly found in the latest group in that the curve of U3 and U4 series are superimposed and differed far away from U5 series curve whose slope of the line is much smaller. Normally slope of U4 series, as one expected, should lie between those of U3 and U5, which may be explained on the basis of possible maximum gas velocity that could bring about a certain upper limit of particles removal rate.

It can be seen from the above results that Wen and Chen model may only applicable to the elutriation rate of fine particle in the size range of smaller than 44 μm in this system investigated. The elutriation rate constants, $E_{i\infty}$ or $ßW/A_c$, of various particle cut sizes were calculated and summarized in Table 5.4.

5.2 Discussions

5.2.1 Effect of superficial gas velocity

Elutriation characteristics have been reviewed by several authors (5,11,12) and it may be concluded that elutriation rate above TDH is affected very strongly by the gas velocity but not the bed hydrodynamics, i.e. minimum fluidized velocity, bubble size or bed internals etc. In this experiment, superficial gas velocities introduce the same effect as one can see when compared the elutriation

Table 5.4 Estimated elutriation rate constant (kg/m²s) and total elutriation rate (kg/m²s) from Wen and Chen's correlation, calculated via ENTRAIN.exe

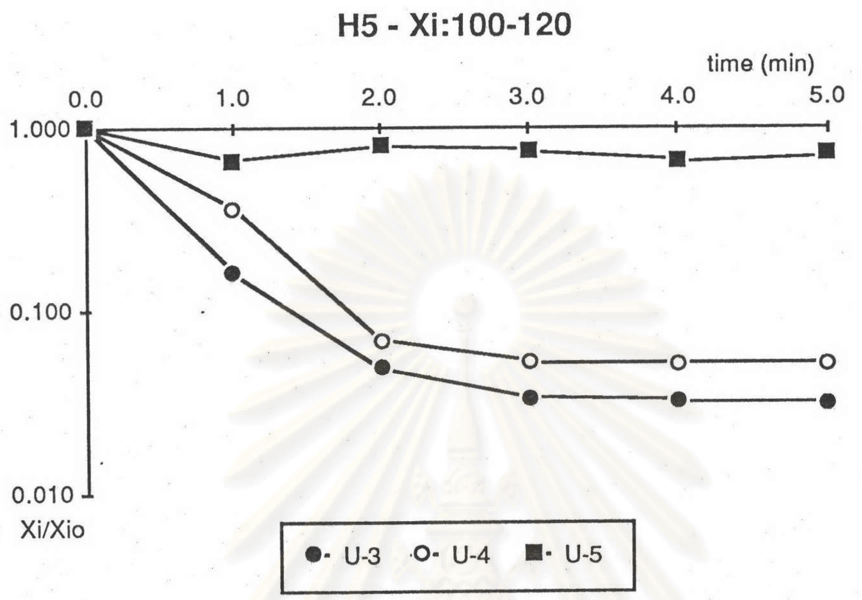
average particle size (μm)	U3		U4		U5	
	$E_{i\infty}$	F_i	$E_{i\infty}$	F_i	$E_{i\infty}$	F_i
22.00	5.728	1.071	5.266	0.974	4.745	0.870
57.45	6.229	0.392	5.580	0.349	4.867	0.302
88.15	5.818	0.152	5.090	0.132	4.298	0.111
114.56	4.95	0.381	4.201	0.324	3.396	0.262
136.47	4.024	0.404	3.287	0.332	2.508	0.257
163.77	2.749	0.227	2.067	0.176	1.371	0.124
212.13	0.631	0.262	0.219	0.168	0.000	0.107
325.96	0.000	0.240	0.000	0.204	0.000	0.167
601.04	0.000	0.780	0.000	0.066	0.000	0.054

rate characteristic of each particle class with different gas velocity, Figure 5.2 (extracted from Appendix F1.1, F2.1, and F3.1). It is expected that only particles with terminal velocity, see Table 4.1, lower than superficial gas velocity could elutriate from the system. Experimental results clearly shows this effect, that is intermediate particles readily elutriated during the initial stage, and fine particles with size smaller than 114.45 μm were gradually elutriated according to the time used, Appendix F.

At the beginning, it was planned to study the effect of gas velocity from 0.7 to 1.2 m/s, but some limitations were found when operation was carried out with gas velocity lower than 1.0 m/s. Under this circumstance, it was observed that there was an immobile zone of powder in the bed, so that fluidization could not thoroughly occur. On the other hand, under condition with gas velocity higher than 1.4 m/s, most of the particles were disengaged out. It may then be concluded, for this case, that operation has to be done within a narrow range of superficial gas velocity of 1.0-1.4 m/s. Therefore, series of superficial gas velocity other than this indicated range were excluded, i.e. U1 = 0.9 m/s and U2 = 1 m/s.

5.2.2 Effect of freeboard height

Thorough examination of curves in Appendix G, obviously shows that the freeboard height of above 1 m have minimal influence on elutriation rate, the height that fall in range of calculated TDH. Lower than 1 m height, effect of entrainment was established especially at the freeboard height of 0.5 m, as seen from Appendix G1.1, G2.1, G3.2 and G3.6. Increase in elutriation rate was probably due to ejection of coarser particles during bubble break and the freeboard height was sufficiently low. Opposite effect was found at H5 for particle class of 100-120 mesh, Appendix G3.3, when height of bed was long enough, the coarser particles,



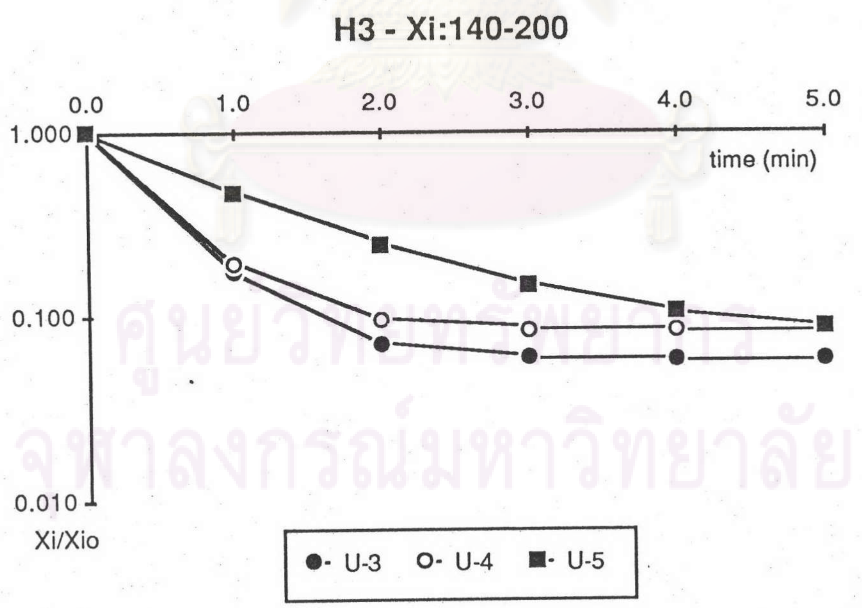


Figure 5.2 Effect of superficial gas velocity on elutriation rate of ocimum seeds powder

for a specified superficial velocity, trend to stabilize in the bed. This phenomena can also investigate from Appendix G3.2.

Lag-phase phenomena was found only at freeboard height above 1 m (Appendix G2.1, G2.2, G2.1, G3.3 and G3.4). It seemed to be the transitional stage between elutriation and stabilization of particles in the bed.

Height of freeboard produced no effect on extremely fine particle, as seen in figure 5.1i, elutriation rate constant at each velocity used was invarient.

5.2.3 Effect of particle size and content

It was previously indicated by Wen and Chen (12) that elutriation rate constant would reach a constant value for small particle. In addition, formerly Leva (5) was reported that $E_{i\infty}$ of fine would decrease when its concentration was more than 25%. Superimposition of curves of smallest group particle in U4 and U5 series, Figure 5.1i, might be due to these characteristics, since this group was considered as extremely fine particles and elutriated content of this system was about 40-50%.

In this experiment, the behavior of fine particles (smaller than 88.15 μm) tend to follow first-order rate fashion as seen in Figure 5.1h and 5.1i. Intermediate -size particles (163.77-114.45 μm cut size) tend to elutriate rapidly at the beginning of operation and becomes stabilized thereafter. This behavior may be attributed to their low content in original powder, see Table 3.5, in which most of these intermediate-size particles were removed with only trace amount, but significant, left in the system after elutriation had begun.

5.2.4 Evidences of particle-particle interaction

Most of models previously reported on entrainment and elutriation on one-kind powder bed were based on the assumption that there was no particle interaction and elutriation occurred at superficial gas velocity larger than particle terminal velocity. In this study several compelling evidences indicating particle-particle interaction were noted as follows;

a) in general, elutriation of intermediate particles would decrease exponentially with increased in freeboard height but this is not the case for this study. In contrary, little effect of freeboard height was found in comparison of elutriation curves in each set of data, as discussed in 5.2.2.

b) even at superficial gas velocity higher than particle terminal velocity, intermediate and coarser particles had the tendency to remain in bed. In addition, elutriation rate constant of smallest particle group experimentally obtained is much lower than calculated value.

c) bed hydrodynamics might have significant influence on elutriation rate especially at the initial stage of operation.

d) as already mentioned that the ocimum powder mixture in this system consisted of three components of particles, one of which is the swellable substance. Even of a small amount of moisture, about 5% content, it may behave as binder and produce effect on fluidization.

5.2.5 Fluidization and elutriation phenomena of ocimum seed powder

Deviation of elutriation rate from first order correlation found in this experiment may be explained on the basis of the following properties;

5.2.5.1 Slug flow characteristics

As discussed earlier, observed minimum fluidizing velocity of this system was far greater than the predicted value. In addition, ocimum seed powder characteristics could be classified into Geldart's group A powder, i.e., ρ_s-ρ_g ≈

1400 with the average particle diameter of 150 μm (see Figure 2.7). Thus, slug flow was thus most likely to occur in the initial stage and actually it did take place, under visual inspection. After slug flow and cloud of particles had been carried upward to freeboard, fluidization changed to normal bubble type. As particles cloud was slowly rising, large particles were falling back into bed meanwhile the continuous applied force still supported intermediate size particles to flow over until they reached the outlet opening and were finally removed from system. This sufficiently provides an explanation of the cause of rapid drop down behavior of intermediate size particle curves. In contrast, during the short period time of applied force from air flow, fine particles could be dispersed from the cloud through out the loose phase of the chamber whereas the intermediate ones could not and still remain in cloud after the air flow was shut down. This results in a delayed effect or lag-phase phenomena because intermediate particles fell back into the bed whereas fine particles were already removed from system during dispersion stage.

5.2.5.2 Elutriation of multi-size powder system

Deviation from first order rate relation was also found when handling with multi-size one-kind powder bed as reported by Hanesian and Rankell (21) as seen in Figure 2.5, who described the elutriation rate as equation 2.23;

$$\frac{X_i}{X_{io}} = be^{-k_1 t} + (1+b)e^{-k_2 t}$$

In this study similar characteristics could be seen as in Figure 5.3, however, for the most part, intermediate size particles have the higher rate than finest particles which deviated from Hanesian and Rankell's study. This may be due to its unique nature of multiple-kind powder bed system.

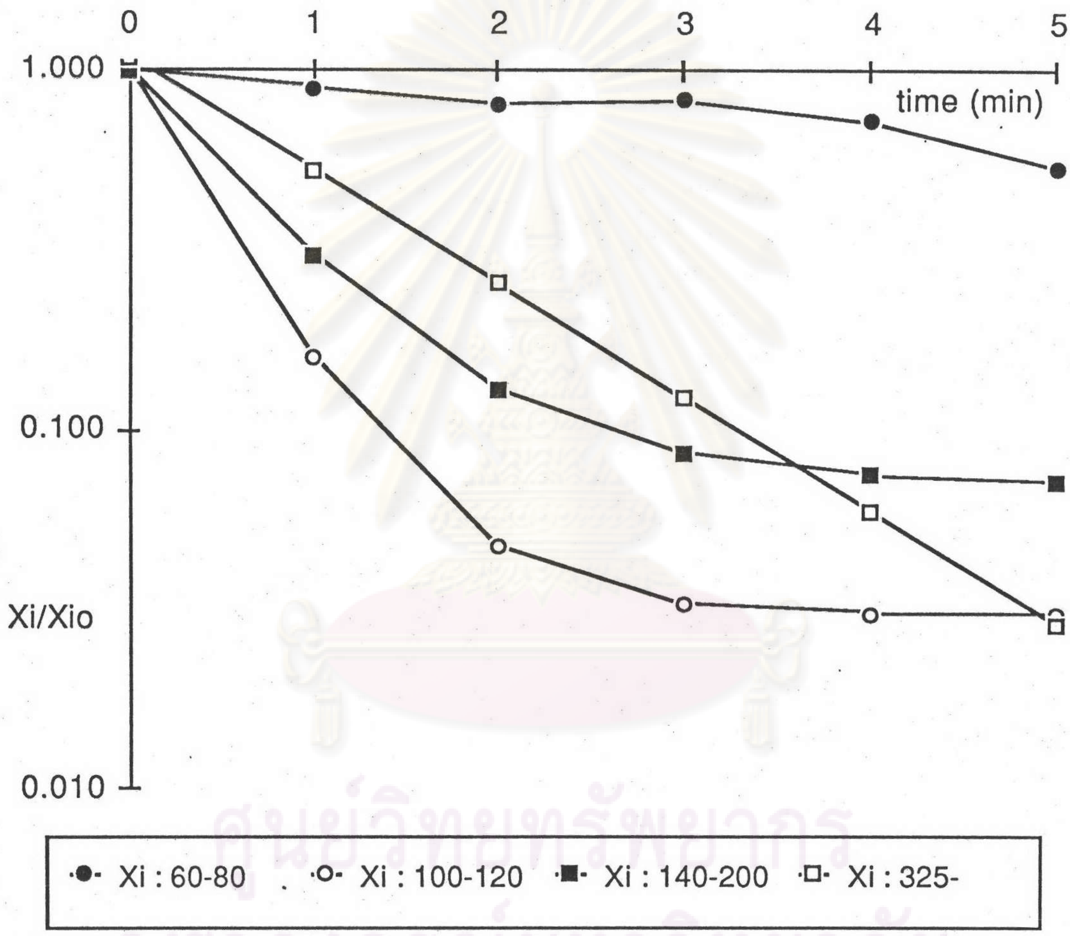


Figure 5.3 Example of ocimum seeds particle rate characteristic curves represent the behavior of multi-size powder bed (extracted from Appendix E)

5.2.5.3 Effect of particle-particle interaction

Another reason contributing to the increase in elutriation rate of intermediate size particle was the effect of particle-particle interaction. According to Geldart *et al* (22), as elutriation was operated with two-kind powder bed. It was found that the coarse particles were forced into the upper reaches of the column as fines were added in spite of the fact that it did not formerly take place.

As mention earlier in chapter 3 the investigation of powder composition revealed 3 different species of particles in this system with highly possible existence of interparticle interactions during fluidizing operation. This was clearly confirmed by the preceding experimental results which indicated that fine particles seems to play an important role in this system studied. This effect may possibly involved in elutriation process which in part brought about an increase in removal rate of intermediate particles.

5.2.6 Elutriation rate correlation

Though, in this study, previously proposed model failed to fit with experimental results, by means of basic concept, upward flow of particles is still the function of gas velocity, particle size, particle density and column height or the height that could be reached by particles. Elutriation rate of this system, which deviates from simple first order relation, may be described by the equation 5.1 or

$$-\frac{dX_i}{dt} = \beta(X_i + AX_{io}) \qquad (5.2)$$

This equation was found to be in good agreement with experimental results, especially for intermediate size particles. The constant βAX_{io} is responsible for the factor contributed to the sudden drop down of curve in the initial stage and was strongly influenced by bed hydrodynamics. For extremely fine particles, this term may be neglected since elutriation rate depended mainly upon superficial velocity and first order rate relation got in place. However, failure in prediction of elutriation rate constant from proposed equation was obtained which might be due to the unique complication of ocimum seed powders. The elutriation rate constants of fine particles fell into the range of 0.0015 to 0.015 kg/m^2s, the later is the upper limit of its value which was much smaller than the calculated value via Wen and Chen's model, Table 5.4.

5.2.7 Classification of ocimum seed powder and operating condition

Practically, classification by elutriation in batch processing method, after having been specified the required particle size range to be removed, key factors for operation are;

- height of column together with superficial velocity, combined effect of which will cause maximized collection of required particles, and
- operating time at which remaining particles in bed are stabilized

For example, according to this experiment, collected particles are in the range of 136.47 μm cut size or larger, it can be seen from figure in Appendix F3.5, height of bed used is H5 and operating gas velocity is U5. Operating time can be calculated from initial mass fraction or weight of smallest group and its slope (see Appendix H) because under this condition declining rate of finest particles is slowest and time used in operation is 16 minutes or more.

Thorough examination of experimental results and above example, classification of ocimum seed powder could be done by this method. Gas velocity seems to have more effect on classifying than height of column. In this system the lower column height at H1 and H2 are not sufficient for separation process because, at the level lower than H2 or TDH, intermediate particles have higher removal rate especially at initial stage. From the level of H3 or upper, results of the same gas velocity operation produce a little effect on classification, but adjustment of gas velocity leads to a significant separation capacity.

To design a fluidized bed for ocimum seed powder in batch processing by mean of elutriation method, it is suggested that height of column should be 1 m or higher. Although empirical correlation could not be developed at this time, for a specified size range of particles, the elutriation rate characteristics in this experiment may be used as a guideline in estimating gas velocity and column height. It is provided that test run should be performed to verify its validity.

In batch processing, it is not necessary to determine the rate characteristics of particles while investigating of operating gas velocity since within first few minutes almost removable particles are lost from system. After that only fine particles gradually elutriate and system becomes unchanged when all of them are exhausted from the column. This terminal phenomena can be directly observed if column body is made of transparent material. Analysis of particles in the left unchanged will determine the separation capacity. Operating time is also determined by this method.

5.2.8 Economic point of view

In terms of economical aspects, it is questionable whether the fluidization process is appropriate in powder classification owing to its considerably high energy consumption. Nevertheless, estimation of power consumption in this case from mechanical energy balance was performed (11), according to the experimental conditions (i.e., U=1.15 m/s, H=1.5 m) and 60 % blower efficiency. It was found that about 0.4 hp or 300 watts would be consumed for this operation. Based on experimental data, for each batch of operation, it took about 30 minutes time to yield about 300 g of product, only approximately 0.15 kw-hr energy was required see detail in Appendix H.This quantity of energy is therefore in the acceptable range on the basis of production cost judgment . In fact, the actual power consumption might be lower than calculated above because of particles being continuously elutriated from system during operation. Furthermore, this process was partially proved to be consumed less time than some others. In addition, when drying is involved along with classification, owing to elutriated particles, energy required for drying might be lower than other processes. From this point of view, it is worth to utilize this unit operation as a tool in ocimum seed powder classification.