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## APPENDIX A

### The Determination of Density by the Density-Gradient Technique

The determination of the density of solid plastics by the density-gradient technique is detailed in ASTM D-1505. The principle of the method is described below.

#### 1. Preparation of density-gradient columns

1.1 Assemble the apparatus as shown in Figure A-1, using beakers of the same diameter. Then select an appropriate amount of two suitable liquids which previously have been carefully deaerated by gentle heating. Typical liquid systems for density-gradient tubes are listed in Table A-1. The volume of the more dense liquid used in the mixer (beaker B shown in Fig. A-1) must be equal to at least one half of the total volume desired in the gradient tube. An estimate of the volume of the less dense liquid required in beaker A to establish flow from A to B can be obtained from the following inequality:

$$V_A > d_B V_B / d_A$$

where:

- $V_A$  = starting liquid volume in beaker A,
- $V_B$  = starting liquid volume in beaker B,
- $d_A$  = density of the starting liquid in beaker A, and
- $d_B$  = density of the starting liquid in beaker B.

A small excess (not exceeding 5%) over the amount indicated by the above equality will induce the required flow from A to B and yield a very nearly linear gradient column.

1.2 Place an appropriate volume of the denser liquid into beaker B of suitable size. Prime the siphon between beaker B and the gradient tube with liquid from beaker B and then close the stopcock. The delivery end of this siphon should be equipped with a capillary tip for flow control.

1.3 Place an appropriate volume of the less dense liquid into beakers A and B with the liquid from beaker A and close the stopcock. Start the highspeed, propeller-type stirrer in beaker B and adjust the speed of stirring such that the surface of the liquid does not fluctuate greatly.

1.4 Start the delivery of the liquid to the gradient tube by opening the two siphon-tube stopcocks simultaneously. Adjust the flow of liquid into the gradient tube at a very slow rate, permitting the liquid to flow down the side of the tube. Fill the tube to the desired level.

## 2. Procedure

2.1 Wet three representative test specimens with the less dense of the two liquids used in the tube and gently place them in the tube. Allow the tube and specimens to reach equilibrium, which will require 10 min or more.

2.2 When a graduated tube is used, read the height of the floats and specimens by using a line through their center of volume. When a cathetometer is used, measure the height of the floats and specimens from an arbitrary level using a line through their center volume. If equilibrium is not obtained, the specimen may be imbibing the liquid.

2.3 Old samples can be removed without destroying the gradient by slowly withdrawing a wire screen basket attached to a long wire. This can be conveniently done by means of a clock motor. Withdraw the basket from the bottom of the tube and, after cleaning, return it to the performed at a slow enough rate (approximately 30 min/300-mm length of column) so that the density gradient is not disturbed.

### 3. Calculation

The densities of the samples may be determined by calculation from the levels to which the samples settle. The densities can be calculated by interpolation as follows.

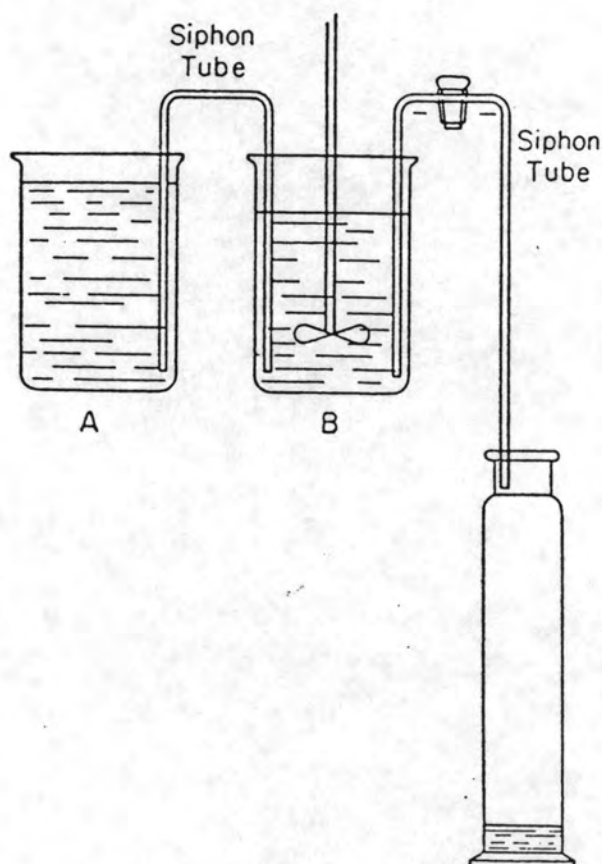
$$\text{Density at } x = a + [(x-y)(b-a)/(z-y)]$$

where

- a and b = densities of the two standard floats.
- y and z = distances of the two standards, a and b, respectively, bracketing the unknown measured from an arbitrary level, and
- x = distance of unknown above the same arbitrary level.

**Table A-1** Liquid System for Density-Gradient Tubes

System	Density Range (g/cm <sup>3</sup> )
Methanol-benzyl alcohol	0.80 to 0.92
Isopropanol-water	0.79 to 1.00
Isopropanol-diethylene glycol	0.79 to 1.11
Ethanol-carbon tetrachloride	0.79 to 1.59
Toluene-carbon tetrachloride	0.87 to 1.59
Water-sodium bromate	1.00 to 1.41
Water-calcium nitrate	1.00 to 1.60
Carbon tetrachloride-trimethylene dibromide	1.60 to 1.99
Trimethylene dibromide-ethylene bromide	1.99 to 2.18
Ethylene bromide-bromoform	2.18 to 2.89

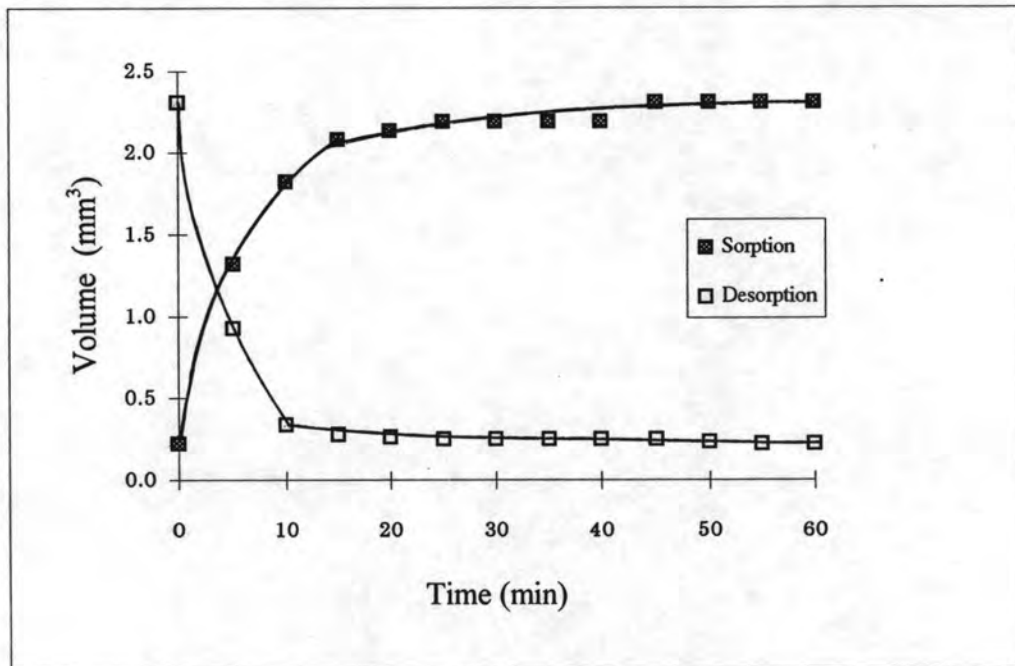
**Figure A-1** Apparatus for gradient tube preparation

## APPENDIX B

### Data of Sorption and Desorption of Toluene by Bead

**Table B-1** Sorption and desorption of toluene by seed bead (C-T0/N1)

Sorption					Desorption		
Time (min)	Bead dia (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol ratio	Bead dia (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.7500	0.2210	-	1.00	1.6389	2.3058	-
5	1.3611	1.3208	0.1222	5.98	1.2083	0.9241	-0.2763
10	1.5139	1.8174	0.0306	8.22	0.8611	0.3345	-0.1179
15	1.5833	2.0791	0.0139	9.41	0.8056	0.2738	-0.0121
20	1.5970	2.1335	0.0027	9.65	0.7917	0.2599	-0.0028
25	1.6111	2.1905	0.0028	9.91	0.7778	0.2464	-0.0027
30	1.6111	2.1905	0.0000	9.91	0.7778	0.2464	0.0000
35	1.6111	2.1905	0.0000	9.91	0.7778	0.2464	0.0000
40	1.6111	2.1905	0.0000	9.91	0.7778	0.2464	0.0000
45	1.6389	2.3058	0.0056	10.43	0.7778	0.2464	0.0000
50	1.6389	2.3058	0.0000	10.43	0.7639	0.2335	-0.0026
55	1.6389	2.3058	0.0000	10.43	0.7500	0.2210	-0.0025
60	1.6389	2.3058	0.0000	10.43	0.7500	0.2210	0.0000

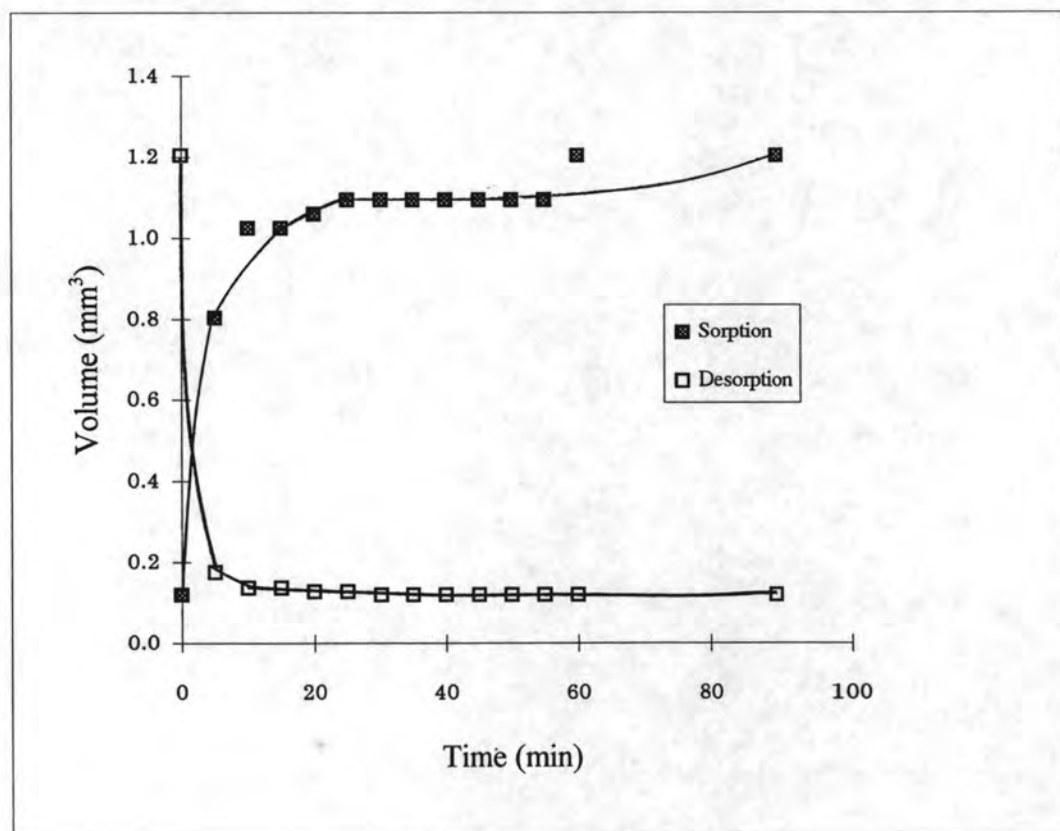


**Figure B-1** Variation of bead volume with time: seed bead (C-T0/N1)



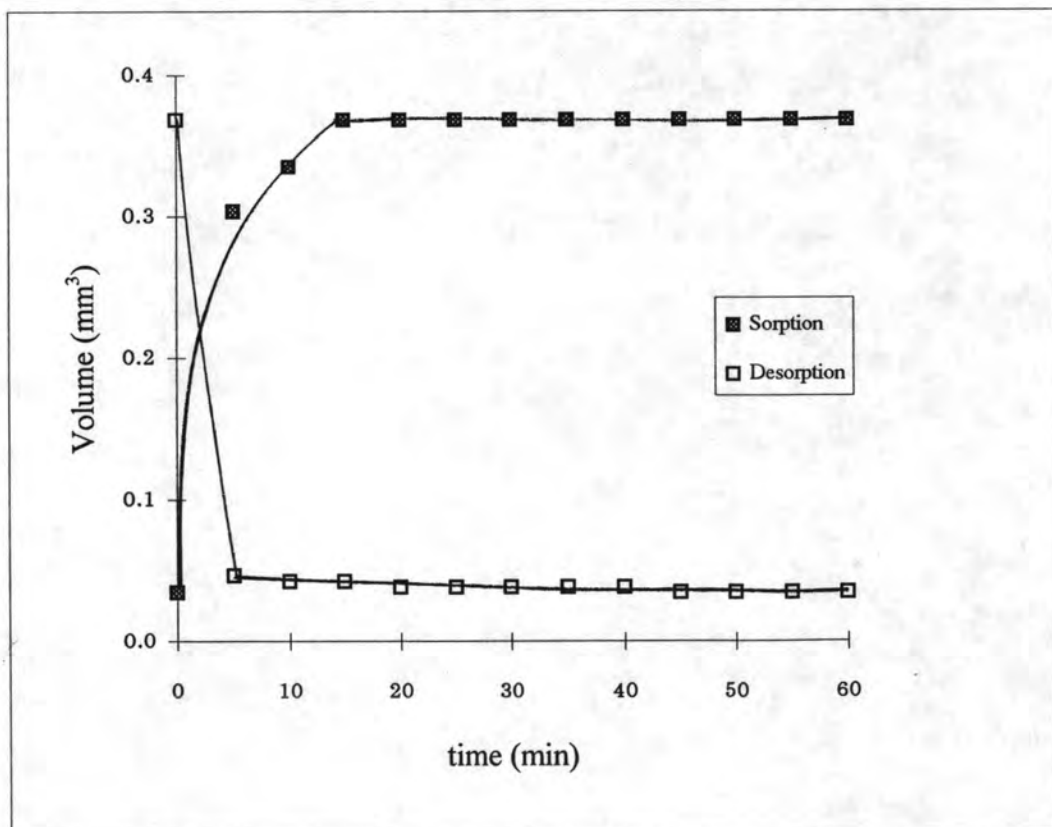
**Table B-2** Sorption and desorption of toluene by seed bead (C-T1/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.6111	0.1195	-	1.00	1.3194	1.2032	-
5	1.1528	0.8024	0.1366	6.71	0.6944	0.1754	-0.2056
10	1.2500	1.0231	0.0441	8.56	0.6389	0.1366	-0.0078
15	1.2500	1.0231	0.0000	8.56	0.6389	0.1366	0.0000
20	1.2639	1.0576	0.0069	8.85	0.6250	0.1279	-0.0017
25	1.2778	1.0928	0.0071	9.14	0.6250	0.1279	0.0000
30	1.2778	1.0928	0.0000	9.14	0.6111	0.1195	-0.0017
35	1.2778	1.0928	0.0000	9.14	0.6111	0.1195	0.0000
40	1.2778	1.0928	0.0000	9.14	0.6111	0.1195	0.0000
45	1.2778	1.0928	0.0000	9.14	0.6111	0.1195	0.0000
50	1.2778	1.0928	0.0000	9.14	0.6111	0.1195	0.0000
55	1.2778	1.0928	0.0000	9.14	0.6111	0.1195	0.0000
60	1.3194	1.2032	0.0221	10.06	0.6111	0.1195	0.0000
90	1.3194	1.2032	0.0000	10.06	0.6111	0.1195	0.0000

**Figure B-2** Variation of bead volume with time : seed bead (C-T1/N1)

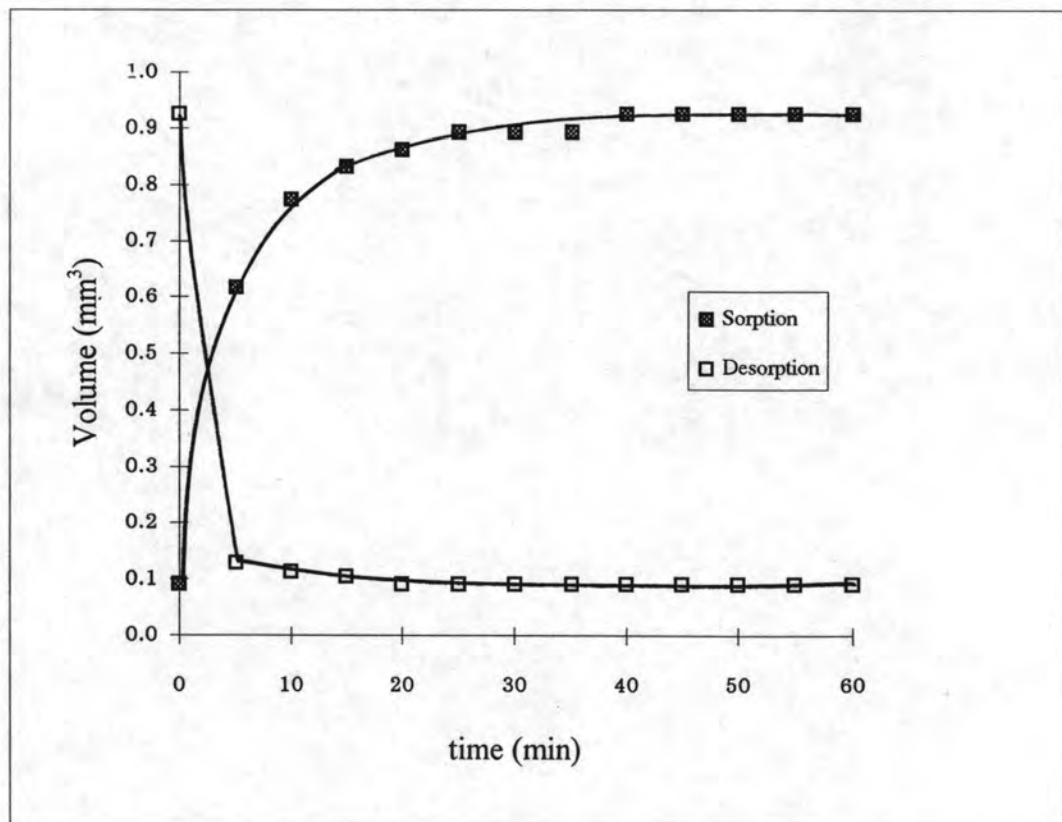
**Table B-3** Sorption and desorption of toluene by seed bead (C-T2/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	vol ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.4028	0.0342	-	1.00	0.8889	0.3679	-
5	0.8333	0.3031	0.0538	8.86	0.4444	0.0460	-0.0644
10	0.8611	0.3345	0.0063	9.77	0.4306	0.0418	-0.0008
15	0.8889	0.3679	0.0067	10.75	0.4306	0.0418	0.0000
20	0.8889	0.3679	0.0000	10.75	0.4167	0.0379	-0.0008
25	0.8889	0.3679	0.0000	10.75	0.4167	0.0379	0.0000
30	0.8889	0.3679	0.0000	10.75	0.4167	0.0379	0.0000
35	0.8889	0.3679	0.0000	10.75	0.4167	0.0379	0.0000
40	0.8889	0.3679	0.0000	10.75	0.4167	0.0379	0.0000
45	0.8889	0.3679	0.0000	10.75	0.4028	0.0342	-0.0007
50	0.8889	0.3679	0.0000	10.75	0.4028	0.0342	0.0000
55	0.8889	0.3679	0.0000	10.75	0.4028	0.0342	0.0000
60	0.8889	0.3679	0.0000	10.75	0.4028	0.0342	0.0000

**Figure B-3** Variation of bead volume with time: seed bead (C-T2/N1)

**Figure B-4** Sorption and desorption of toluene by seed bead (C-T3/N1)

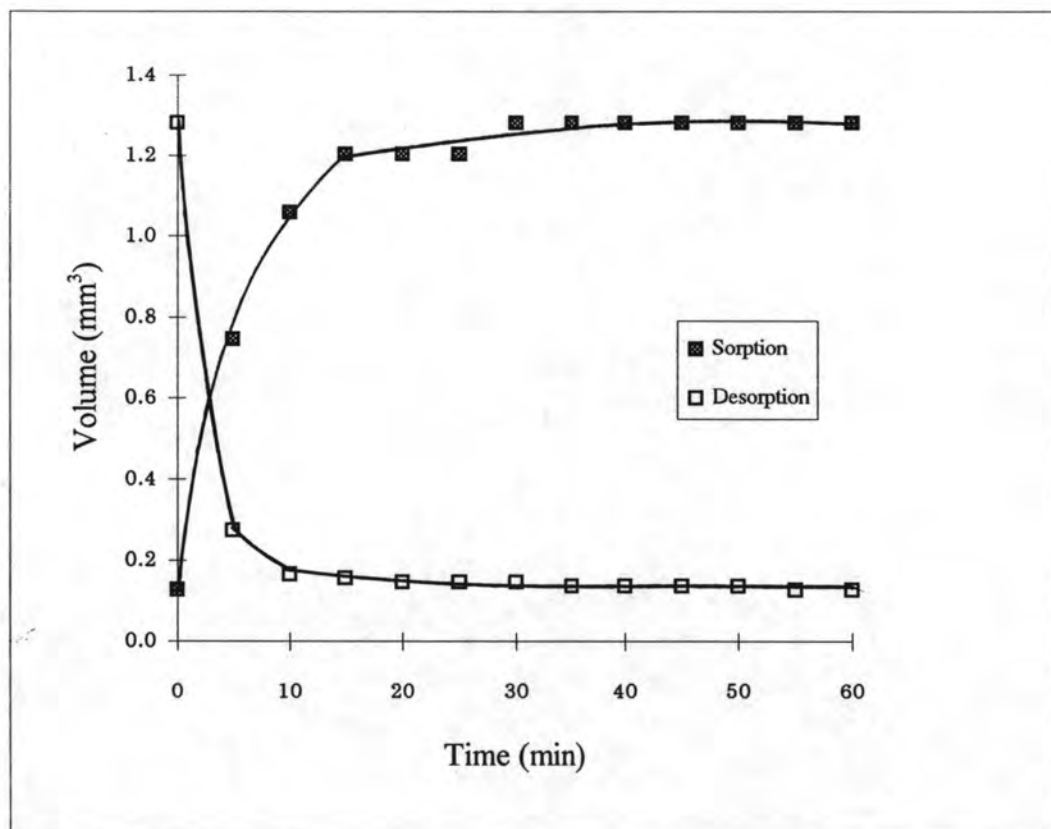
Time (min)	Sorption				Desorption		
	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.5556	0.0898	-	1.00	1.2083	0.9241	-
5	1.0556	0.6161	0.1052	6.86	0.6250	0.1279	-0.1592
10	1.1389	0.7738	0.0315	8.62	0.5972	0.1116	-0.0033
15	1.1667	0.8318	0.0116	9.26	0.5833	0.1040	-0.0015
20	1.1806	0.8619	0.0060	9.60	0.5556	0.0898	-0.0028
25	1.1944	0.8926	0.0062	9.94	0.5556	0.0898	0.0000
30	1.1944	0.8926	0.0000	9.94	0.5556	0.0898	0.0000
35	1.1944	0.8926	0.0000	9.94	0.5556	0.0898	0.0000
40	1.2083	0.9241	0.0063	10.29	0.5556	0.0898	0.0000
45	1.2083	0.9241	0.0000	10.29	0.5556	0.0898	0.0000
50	1.2083	0.9241	0.0000	10.29	0.5556	0.0898	0.0000
55	1.2083	0.9241	0.0000	10.29	0.5556	0.0898	0.0000
60	1.2083	0.9241	0.0000	10.29	0.5556	0.0898	0.0000



**Figure B-4** Variation of bead volume with time: seed bead (C-T3/N1)

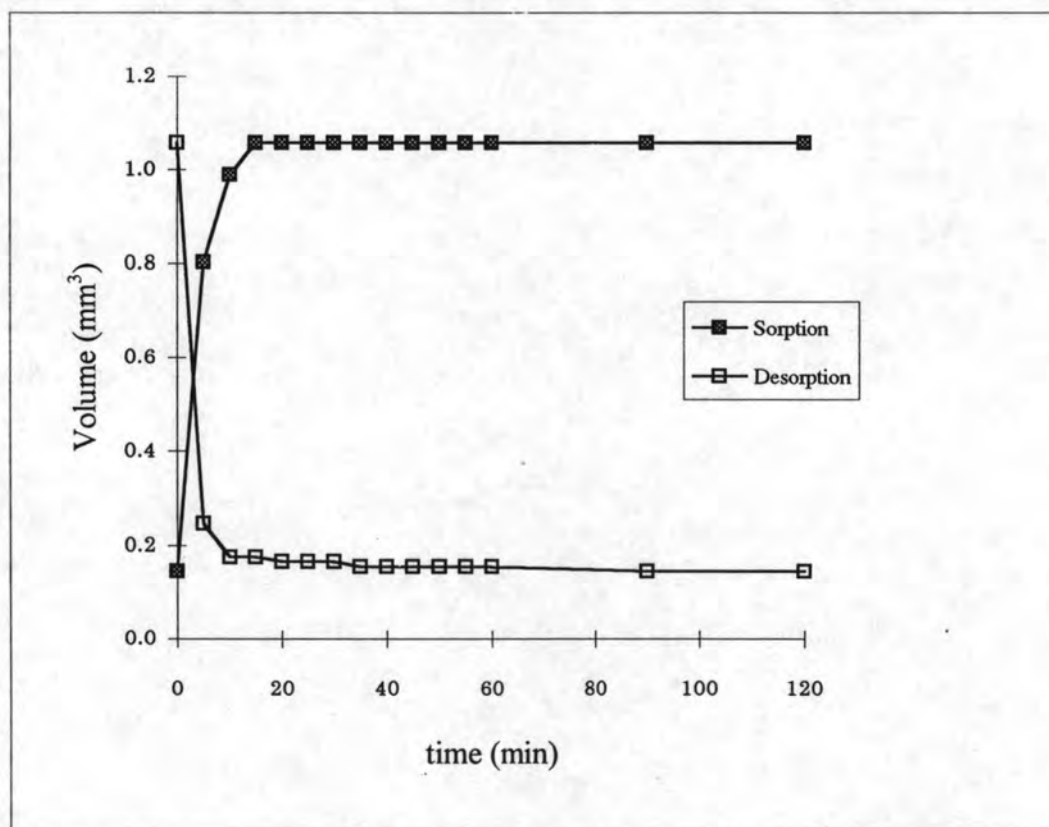
**Table B-5** Sorption and desorption of toluene by seed bead (C-T0/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.6250	0.1279	-	1.00	1.3472	1.2808	-
5	1.1250	0.7458	0.1236	5.83	0.8056	0.2738	-0.2014
10	1.2639	1.0576	0.0623	8.27	0.6806	0.1651	-0.0217
15	1.3194	1.2032	0.0291	9.41	0.6667	0.1552	-0.0020
20	1.3194	1.2032	0.0000	9.41	0.6528	0.1457	-0.0019
25	1.3194	1.2032	0.0000	9.41	0.6528	0.1457	0.0000
30	1.3472	1.2808	0.0155	10.02	0.6528	0.1457	0.0000
35	1.3472	1.2808	0.0000	10.02	0.6389	0.1366	-0.0018
40	1.3472	1.2808	0.0000	10.02	0.6389	0.1366	0.0000
45	1.3472	1.2808	0.0000	10.02	0.6389	0.1366	0.0000
50	1.3472	1.2808	0.0000	10.02	0.6389	0.1366	0.0000
55	1.3472	1.2808	0.0000	10.02	0.6250	0.1279	-0.0017
60	1.3472	1.2808	0.0000	10.02	0.6250	0.1279	0.0000

**Figure B-5** Variation of bead volume with time: seed bead (C-T0/N2)

**Table B-6** Sorption and desorption of toluene by seed bead (C-T1/N2)

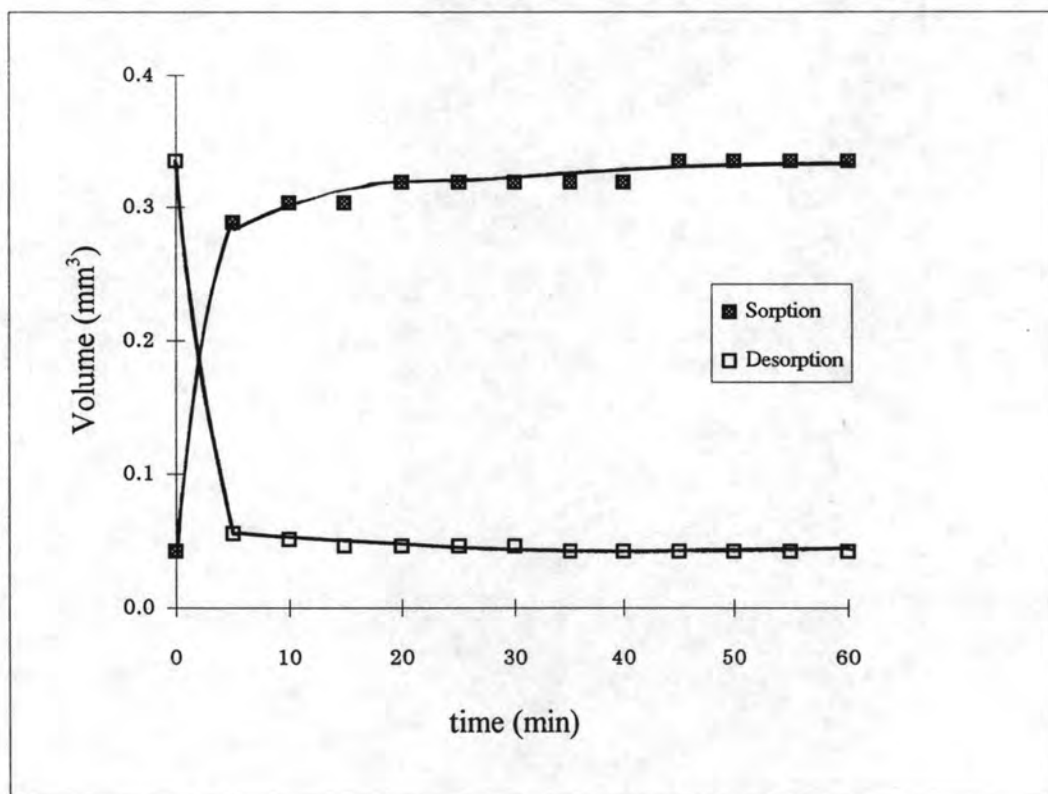
Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.6528	0.1457	-	1.00	1.2639	1.0576	-
5	1.1528	0.8024	0.1313	5.51	0.7778	0.2465	-0.1622
10	1.2361	0.9893	0.0374	6.79	0.6944	0.1754	-0.0142
15	1.2639	1.0576	0.0136	7.26	0.6944	0.1754	0.0000
20	1.2639	1.0576	0.0000	7.26	0.6806	0.1651	-0.0021
25	1.2639	1.0576	0.0000	7.26	0.6806	0.1651	0.0000
30	1.2639	1.0576	0.0000	7.26	0.6806	0.1651	0.0000
35	1.2639	1.0576	0.0000	7.26	0.6667	0.1552	-0.0020
40	1.2639	1.0576	0.0000	7.26	0.6667	0.1552	0.0000
45	1.2639	1.0576	0.0000	7.26	0.6667	0.1552	0.0000
50	1.2639	1.0576	0.0000	7.26	0.6667	0.1552	0.0000
55	1.2639	1.0576	0.0000	7.26	0.6667	0.1552	0.0000
60	1.2639	1.0576	0.0000	7.26	0.6667	0.1552	0.0000
90	1.2639	1.0576	0.0000	7.26	0.6528	0.1457	-0.0003
120	1.2639	1.0576	0.0000	7.26	0.6528	0.1457	0.0000

**Figure B-6** Variation of bead volume with time: seed bead (C-T1/N2)



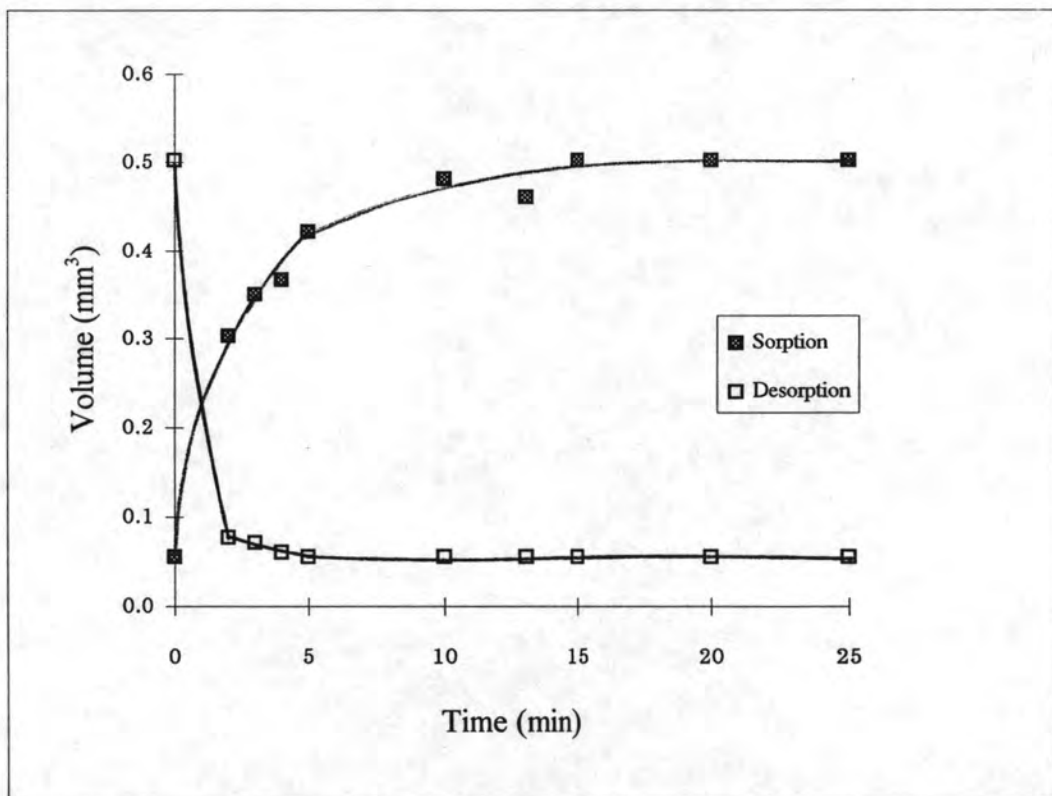
**Table B-7** Sorption and desorption of toluene by seed bead (C-T2/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	vol ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.4306	0.0418	-	1.00	0.8611	0.3345	-
5	0.8194	0.2882	0.0493	6.89	0.4722	0.0552	-0.0559
10	0.8333	0.3031	0.0030	7.25	0.4583	0.0504	-0.0009
15	0.8333	0.3031	0.0000	7.25	0.4444	0.0460	-0.0009
20	0.8472	0.3185	0.0031	7.62	0.4444	0.0460	0.0000
25	0.8472	0.3185	0.0000	7.62	0.4444	0.0460	0.0000
30	0.8472	0.3185	0.0000	7.62	0.4444	0.0460	0.0000
35	0.8472	0.3185	0.0000	7.62	0.4306	0.0418	-0.0008
40	0.8472	0.3185	0.0000	7.62	0.4306	0.0418	0.0000
45	0.8611	0.3345	0.0032	8.00	0.4306	0.0418	0.0000
50	0.8611	0.3345	0.0000	8.00	0.4306	0.0418	0.0000
55	0.8611	0.3345	0.0000	8.00	0.4306	0.0418	0.0000
60	0.8611	0.3345	0.0000	8.00	0.4306	0.0418	0.0000

**Figure B-7** Variation of bead volume with time: seed bead (C-T2/N2)

**Figure B-8** Sorption and desorption of toluene by seed bead (C-T3/N2)

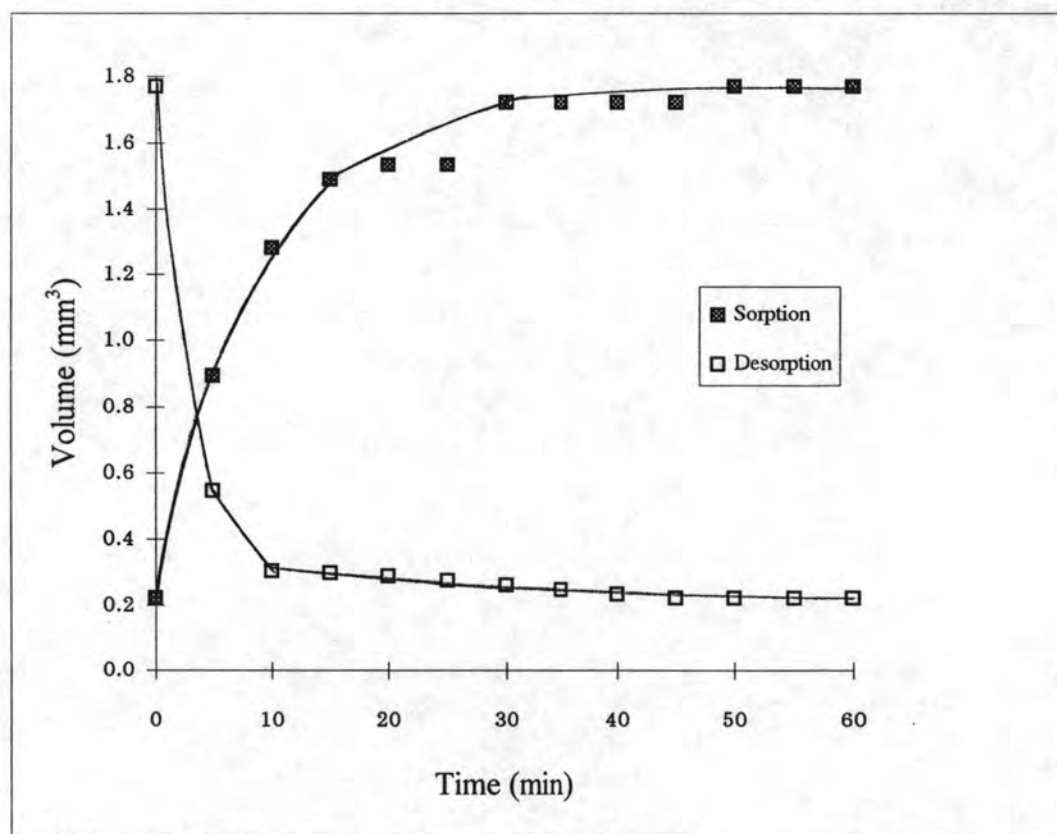
Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.4722	0.0552	-	1.00	0.9861	0.5023	-
2	0.8333	0.3031	0.0496	5.50	0.5278	0.0770	-0.0851
3	0.8750	0.3509	0.0096	6.36	0.5139	0.0711	-0.0012
4	0.8889	0.3679	0.0034	6.67	0.4861	0.0602	-0.0022
5	0.9306	0.4221	0.0108	7.65	0.4722	0.0552	-0.0010
13	0.9583	0.4610	0.0078	8.36	0.4722	0.0552	0.0000
10	0.9722	0.4814	0.0041	8.73	0.4722	0.0552	0.0000
15	0.9861	0.5023	0.0042	9.11	0.4722	0.0552	0.0000
20	0.9861	0.5023	0.0000	9.11	0.4722	0.0552	0.0000
25	0.9861	0.5023	0.0000	9.11	0.4722	0.0552	0.0000



**Figure B-8** Variation of bead volume with time: seed bead (C-T3/N2)

**Table B-9** Sorption and desorption of toluene by seed bead (C-T0/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.7500	0.2210	-	1.00	1.5000	1.7679	-
5	1.1944	0.8926	0.1343	4.04	1.0139	0.5459	-0.2444
10	1.3472	1.2808	0.0776	5.80	0.8333	0.3031	-0.0486
15	1.4167	1.4893	0.0417	6.74	0.8278	0.2971	-0.0012
20	1.4306	1.5335	0.0088	6.94	0.8194	0.2882	-0.0018
25	1.4306	1.5335	0.0000	6.94	0.8056	0.2738	-0.0029
30	1.4861	1.7192	0.0371	7.78	0.7917	0.2599	-0.0028
35	1.4861	1.7192	0.0000	7.78	0.7778	0.2465	-0.0027
40	1.4861	1.7192	0.0000	7.78	0.7639	0.2335	-0.0026
45	1.4861	1.7192	0.0000	7.78	0.7500	0.2210	-0.0025
50	1.5000	1.7679	0.0097	8.00	0.7500	0.2210	0.0000
55	1.5000	1.7679	0.0000	8.00	0.7500	0.2210	0.0000
60	1.5000	1.7679	0.0000	8.00	0.7500	0.2210	0.0000

**Figure B-9** Variation of bead volume with time : seed bead (C-T0/N3)

**Table B-10** Sorption and desorption of toluene by seed bead (C-T1/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.6944	0.1754	-	1.00	1.2917	1.1288	-
5	1.0972	0.6919	0.1033	3.94	0.7778	0.2465	-0.1765
10	1.2083	0.9241	0.0464	5.27	0.7361	0.2089	-0.0075
15	1.2361	0.9893	0.0130	5.64	0.7222	0.1973	-0.0023
20	1.2500	1.0231	0.0067	5.83	0.7083	0.1862	-0.0022
25	1.2611	1.0506	0.0055	5.99	0.7083	0.1862	0.0000
30	1.2611	1.0506	0.0000	5.99	0.7083	0.1862	0.0000
35	1.2778	1.0928	0.0084	6.23	0.6944	0.1754	-0.0021
40	1.2778	1.0928	0.0000	6.23	0.6944	0.1754	0.0000
45	1.2917	1.1288	0.0072	6.43	0.6944	0.1754	0.0000
50	1.2917	1.1288	0.0000	6.43	0.6944	0.1754	0.0000
55	1.2917	1.1288	0.0000	6.43	0.6944	0.1754	0.0000
60	1.2917	1.1288	0.0000	6.43	0.6944	0.1754	0.0000

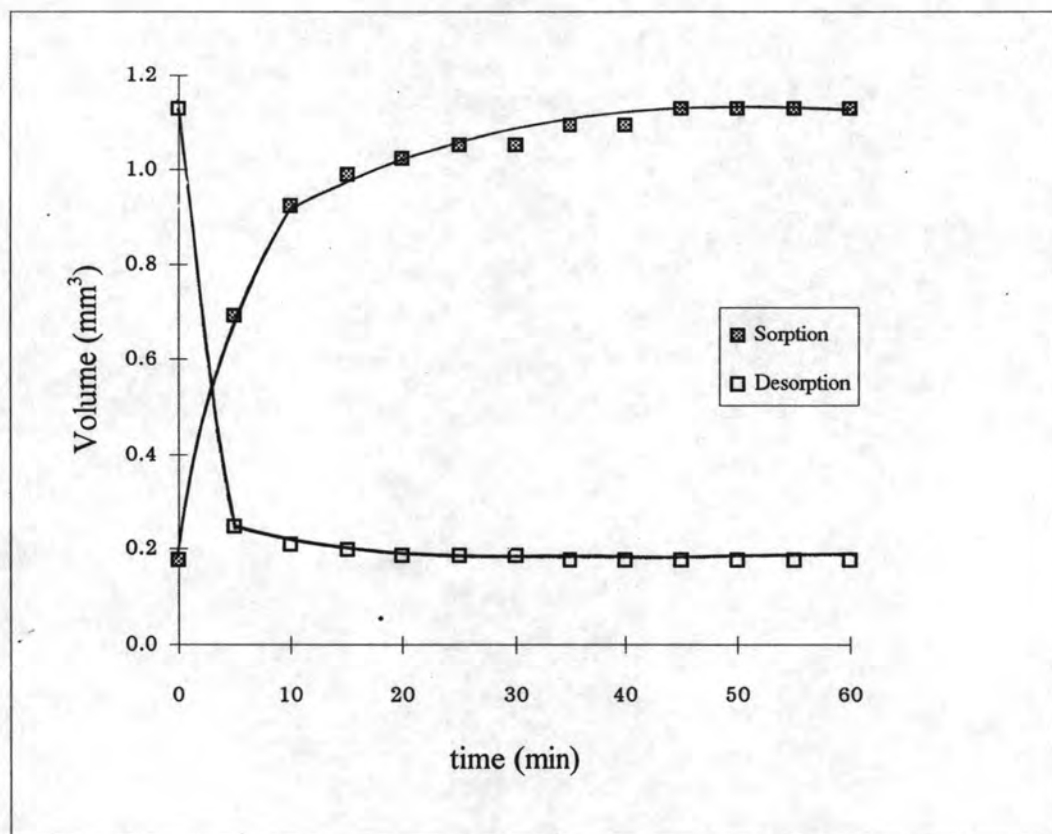
**Figure B-10** Variation of bead volume with time: seed bead (C-T1/N3)

Figure B-11 Sorption and desorption of toluene by seed bead (C-T2/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.6111	0.1195	-	1.00	1.3750	1.3617	-
5	1.1806	0.8619	0.1485	7.21	0.6944	0.1754	-0.2373
10	1.3056	1.1656	0.0608	9.75	0.6250	0.1279	-0.0095
15	1.3333	1.2416	0.0152	10.39	0.6111	0.1195	-0.0017
20	1.3611	1.3208	0.0158	11.05	0.6111	0.1195	0.0000
25	1.3611	1.3208	0.0000	11.05	0.6111	0.1195	0.0000
30	1.3611	1.3208	0.0000	11.05	0.6111	0.1195	0.0000
35	1.3611	1.3208	0.0000	11.05	0.6111	0.1195	0.0000
40	1.3750	1.3617	0.0082	11.39	0.6111	0.1195	0.0000
45	1.3750	1.3617	0.0000	11.39	0.6111	0.1195	0.0000
50	1.3750	1.3617	0.0000	11.39	0.6111	0.1195	0.0000
55	1.3750	1.3617	0.0000	11.39	0.6111	0.1195	0.0000
60	1.3750	1.3617	0.0000	11.39	0.6111	0.1195	0.0000

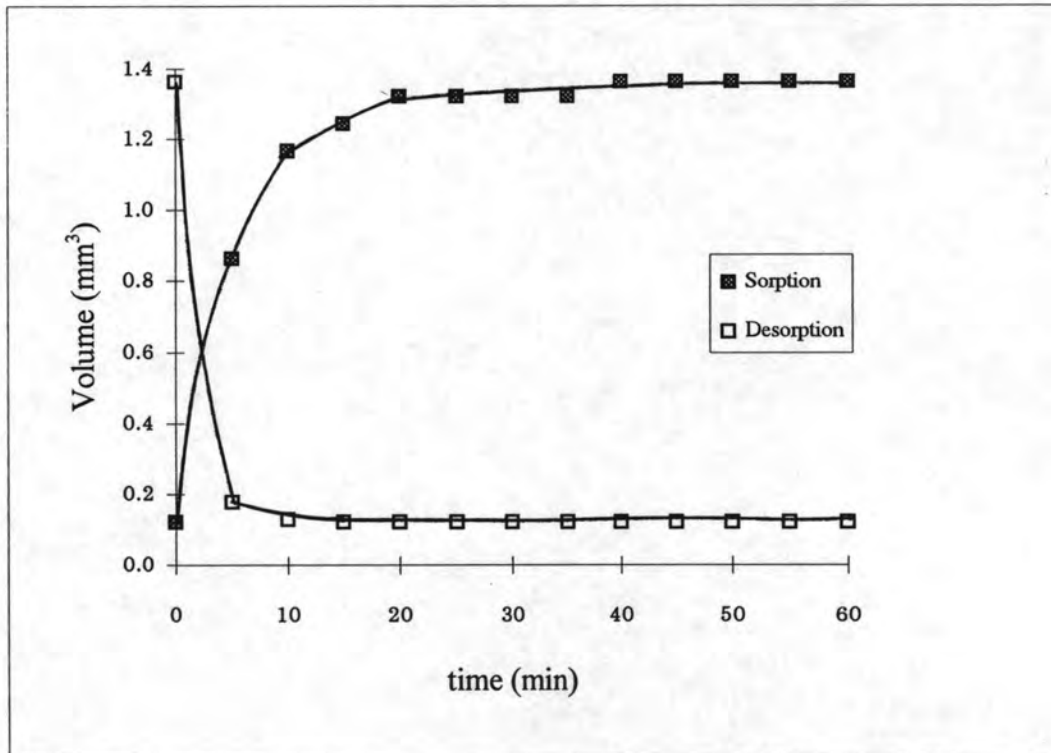
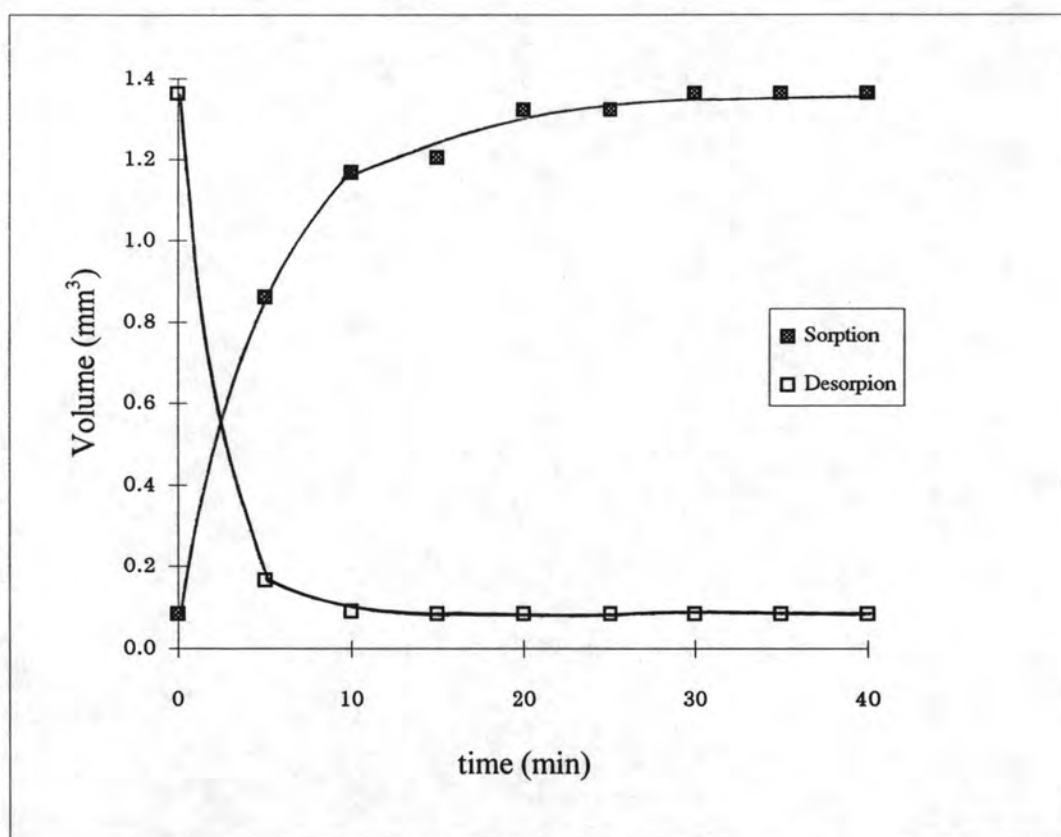


Figure B-11 Variation of bead volume with time: seed bead (C-T2/N3)



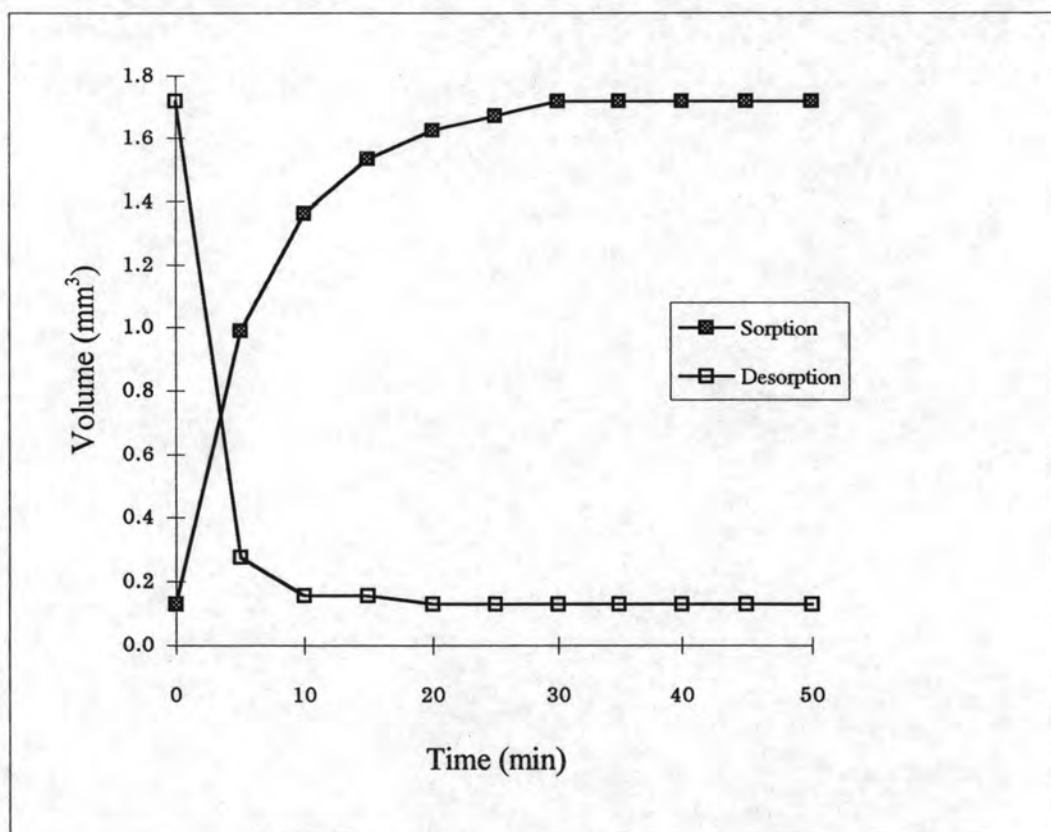
**Figure B-12** Sorption and desorption of toluene by seed bead (C-T3/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.5417	0.0833	-	1.00	1.3750	1.3617	-
5	1.1806	0.8619	0.1557	10.35	0.6806	0.1651	-0.2393
10	1.3056	1.1656	0.0608	13.99	0.5556	0.0898	-0.0151
15	1.3194	1.2032	0.0075	14.44	0.5417	0.0832	-0.0013
20	1.3611	1.3208	0.0235	15.86	0.5417	0.0832	0.0000
25	1.3611	1.3208	0.0000	15.86	0.5417	0.0832	0.0000
30	1.3750	1.3617	0.0082	16.35	0.5417	0.0832	0.0000
35	1.3750	1.3617	0.0000	16.35	0.5417	0.0832	0.0000
40	1.3750	1.3617	0.0000	16.35	0.5417	0.0832	0.0000

**Figure B-12** Variation of bead volume with time: seed bead (C-T3/N3)

**Figure B-13** Sorption and desorption of toluene: seed bead (C-H1/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.6250	0.1279	-	1.00	1.4861	1.7192	-
5	1.2361	0.9893	0.1723	7.74	0.8056	0.2738	-0.2891
10	1.3750	1.3617	0.0745	10.65	0.6667	0.1552	-0.0237
15	1.4306	1.5335	0.0344	11.99	0.6667	0.1552	0.0000
20	1.4583	1.6246	0.0182	12.70	0.6250	0.1279	-0.0055
25	1.4722	1.6714	0.0094	13.07	0.6250	0.1279	0.0000
30	1.4861	1.7192	0.0096	13.44	0.6250	0.1279	0.0000
35	1.4861	1.7192	0.0000	13.44	0.6250	0.1279	0.0000
40	1.4861	1.7192	0.0000	13.44	0.6250	0.1279	0.0000
45	1.4861	1.7192	0.0000	13.44	0.6250	0.1279	0.0000
50	1.4861	1.7192	0.0000	13.44	0.6250	0.1279	0.0000

**Figure B-13** Variation of bead volume with time: seed bead (C-H1/N1)

**Figure B-14** Sorption and desorption of toluene by seed bead (C-H2/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.4722	0.0552	-	1.00	1.0556	0.6161	-
5	1.0000	0.5238	0.0937	9.50	0.5278	0.0770	-0.1078
10	1.0278	0.5687	0.0090	10.31	0.5000	0.0655	-0.0023
15	1.0417	0.5921	0.0047	10.73	0.5000	0.0655	0.0000
20	1.0417	0.5921	0.0000	10.73	0.5000	0.0655	0.0000
25	1.0556	0.6161	0.0048	11.17	0.4722	0.0552	-0.0021
30	1.0556	0.6161	0.0000	11.17	0.4722	0.0552	0.0000
35	1.0556	0.6161	0.0000	11.17	0.4722	0.0552	0.0000
40	1.0556	0.6161	0.0000	11.17	0.4722	0.0552	0.0000
45	1.0556	0.6161	0.0000	11.17	0.4722	0.0552	0.0000
50	1.0556	0.6161	0.0000	11.17	0.4722	0.0552	0.0000
55	1.0556	0.6161	0.0000	11.17	0.4722	0.0552	0.0000
60	1.0556	0.6161	0.0000	11.17	0.4722	0.0552	0.0000

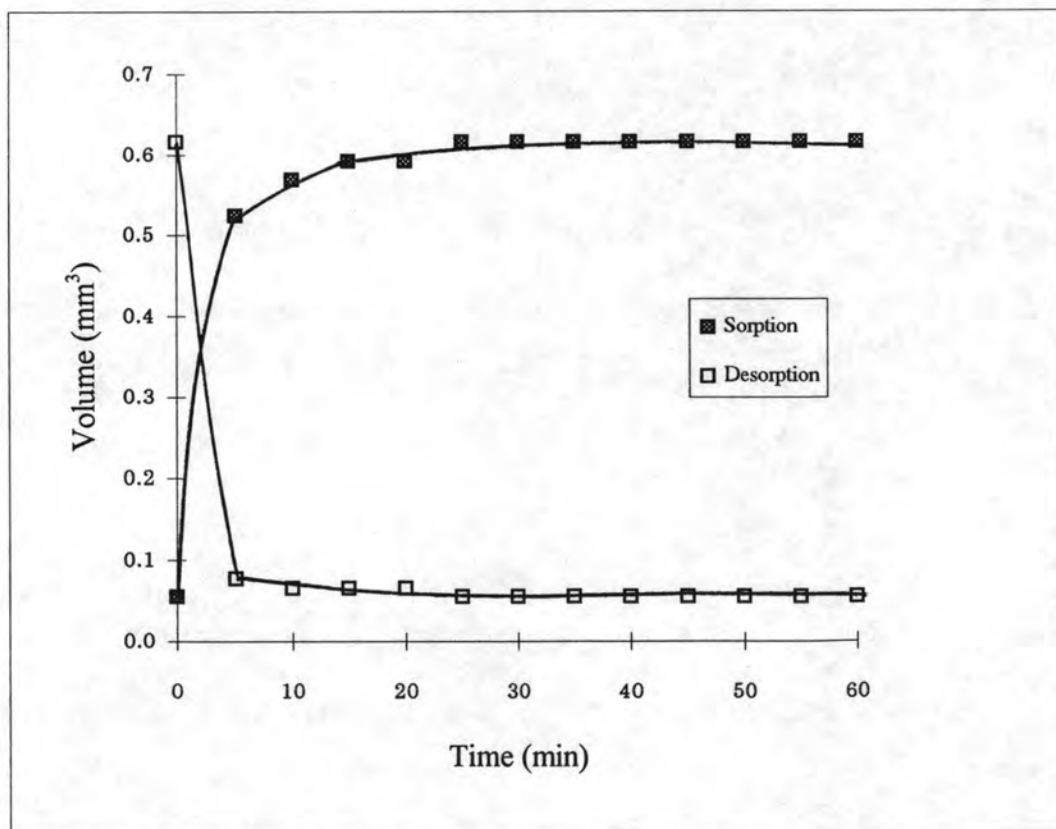
**Figure B-14** Variation of bead volume with time: seed bead (C-H2/N1)

Figure B-15 Sorption and desorption of toluene by seed bead (C-H3/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.8750	0.3509	-	1.00	1.7222	2.6757	-
5	1.3333	1.2416	0.1781	3.54	1.2222	0.9564	-0.3439
10	1.4583	1.6246	0.0766	4.63	1.0000	0.5238	-0.0865
15	1.5000	1.7679	0.0287	5.04	0.9444	0.4413	-0.0165
20	1.5278	1.8679	0.0200	5.32	0.9167	0.4035	-0.0076
25	1.5556	1.9717	0.0208	5.62	0.9167	0.4035	0.0000
30	1.5556	1.9717	0.0000	5.62	0.9028	0.3854	-0.0036
35	1.6667	2.4251	0.0907	6.91	0.9028	0.3854	0.0000
40	1.6667	2.4251	0.0000	6.91	0.8889	0.3679	-0.0035
45	1.6974	2.5619	0.0274	7.30	0.8889	0.3679	0.0000
50	1.7222	2.6757	0.0228	7.63	0.8889	0.3679	0.0000
55	1.7222	2.6757	0.0000	7.63	0.8889	0.3679	0.0000
60	1.7222	2.6757	0.0000	7.63	0.8750	0.3509	-0.0034

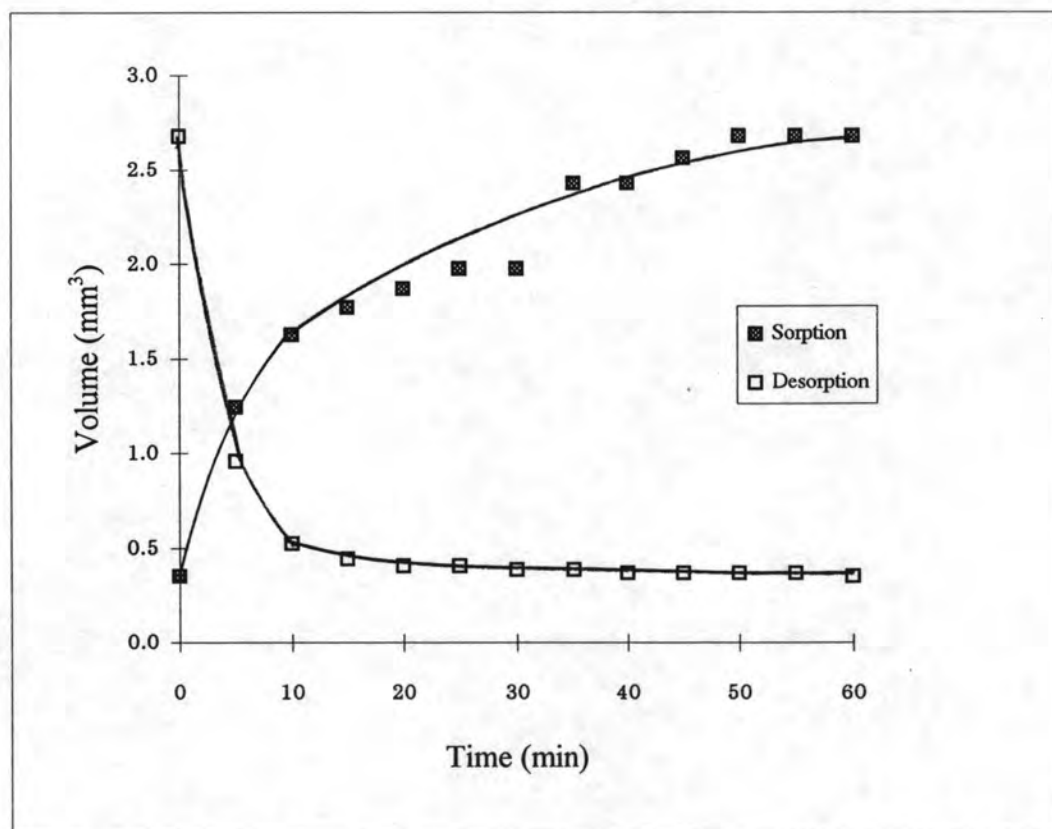
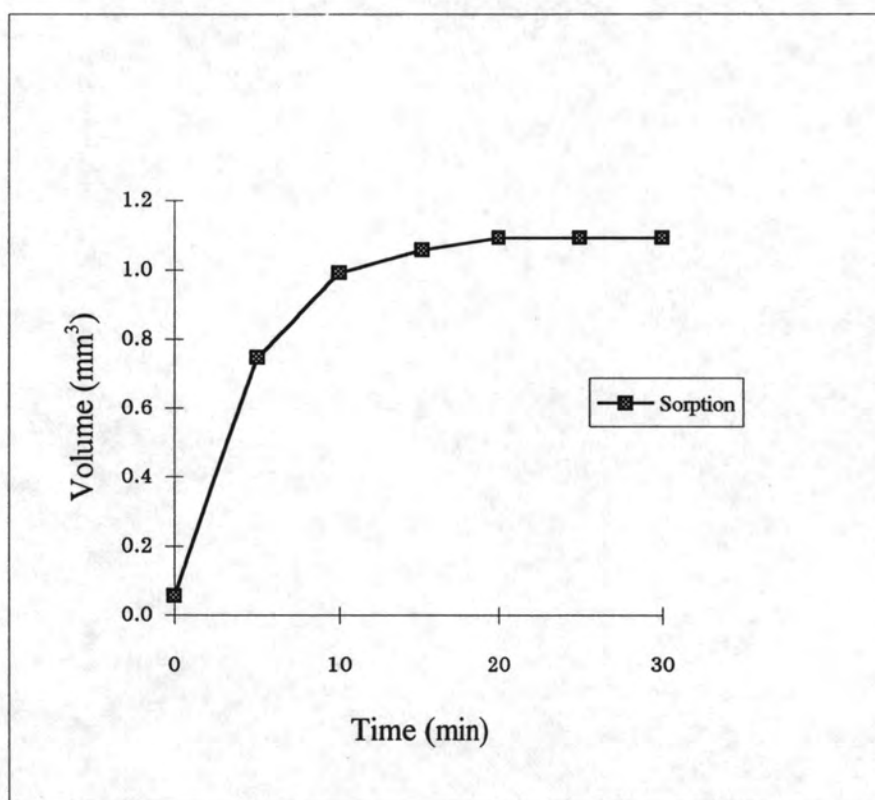


Figure B-15 Variation of bead volume with time: seed bead (C-H3/N1)

**Figure B-16** Sorption and desorption of toluene by seed bead (C-H1/N2)

Sorption				
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio
0	0.4722	0.0552	-	1.00
5	1.1250	0.7458	0.1381	13.52
10	1.2361	0.9893	0.0487	17.94
15	1.2639	1.0576	0.0136	19.17
20	1.2778	1.0928	0.0071	19.81
25	1.2778	1.0928	0.0000	19.81
30	1.2778	1.0928	0.0000	19.81

The bead collapsed in desorption process.

**Figure B-16** Variation of bead volume with time: seed bead (C-H1/N2)



**Figure B-17** Sorption and desorption of toluene by seed bead (C-H2/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.5000	0.0655	-	1.00	1.2500	1.0231	-
5	1.1389	0.7738	0.1417	11.82	0.5417	0.0832	-0.1880
10	1.1944	0.8926	0.0238	13.63	0.5000	0.0655	-0.0036
15	1.2222	0.9564	0.0127	14.61	0.5000	0.0655	0.0000
20	1.2361	0.9893	0.0066	15.11	0.5000	0.0655	0.0000
25	1.2361	0.9893	0.0000	15.11	0.5000	0.0655	0.0000
30	1.2500	1.0231	0.0067	15.63	0.5000	0.0655	0.0000
35	1.2500	1.0231	0.0000	15.63	0.5000	0.0655	0.0000
40	1.2500	1.0231	0.0000	15.63	0.5000	0.0655	0.0000
45	1.2500	1.0231	0.0000	15.63	0.5000	0.0655	0.0000

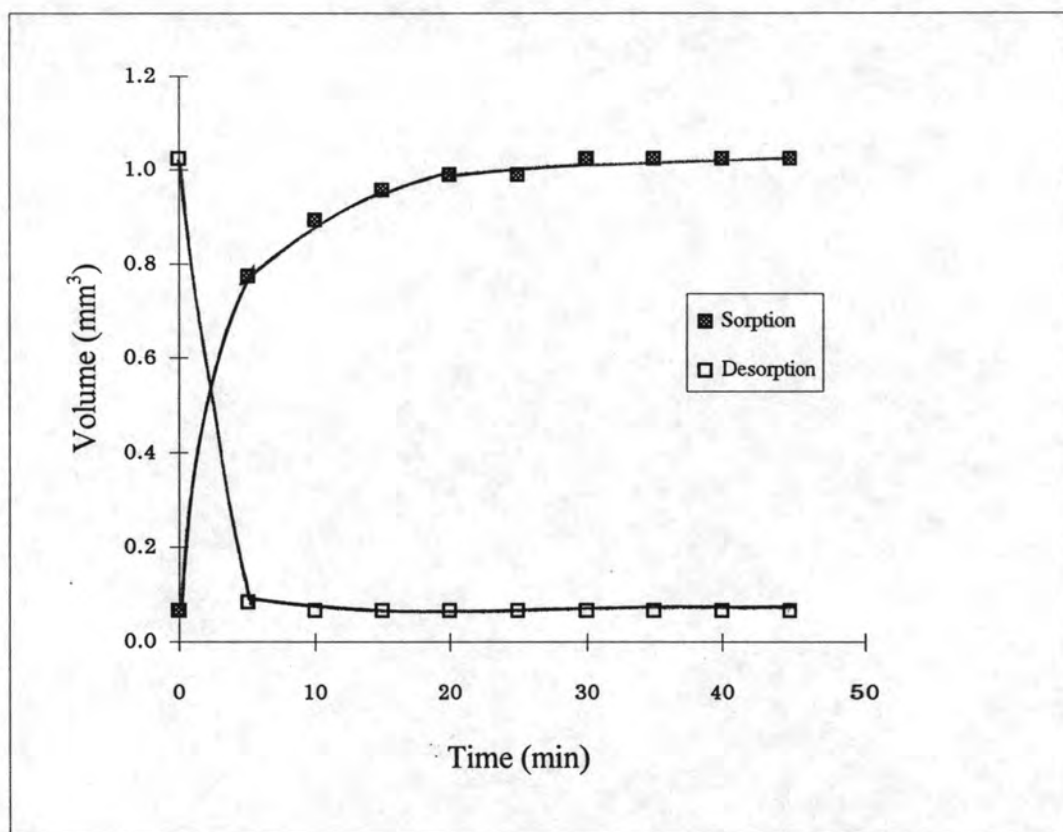
**Figure B-17** Variation of bead volume with time: seed bead (C-H2/N2)

Figure B-18 Sorption and desorption of toluene by seed bead (C-H3/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.4722	0.0552	-	1.00	1.1389	0.7738	-
5	1.0417	0.5921	0.1074	10.73	0.5694	0.0967	-0.1354
10	1.1250	0.7458	0.0308	13.52	0.5278	0.0770	-0.0039
15	1.1389	0.7738	0.0056	14.03	0.5139	0.0711	-0.0012
20	1.1389	0.7738	0.0000	14.03	0.5139	0.0711	0.0000
25	1.1389	0.7738	0.0000	14.03	0.5139	0.0711	0.0000
30	1.1389	0.7738	0.0000	14.03	0.5000	0.0655	-0.0011
35	1.1389	0.7738	0.0000	14.03	0.4861	0.0602	-0.0011
40	1.1389	0.7738	0.0000	14.03	0.4722	0.0552	-0.0010
45	1.1389	0.7738	0.0000	14.03	0.4722	0.0552	0.0000
50	1.1389	0.7738	0.0000	14.03	0.4722	0.0552	0.0000
55	1.1389	0.7738	0.0000	14.03	0.4722	0.0552	0.0000
60	1.1389	0.7738	0.0000	14.03	0.4722	0.0552	0.0000

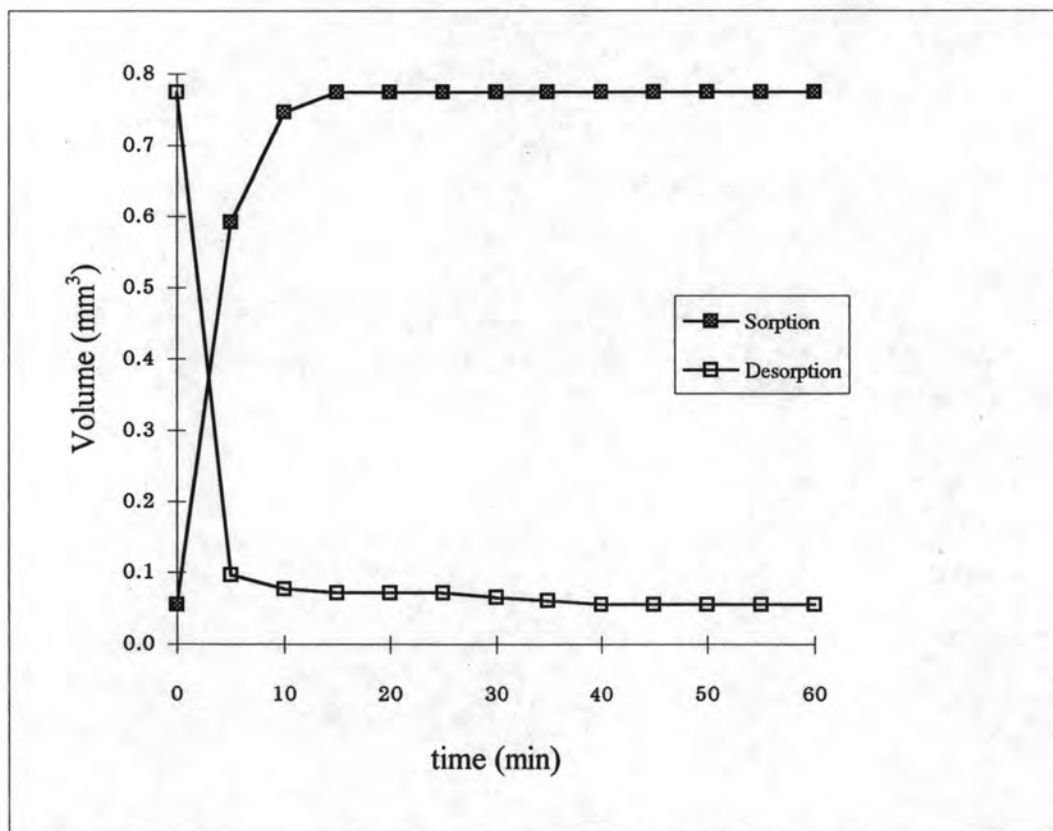
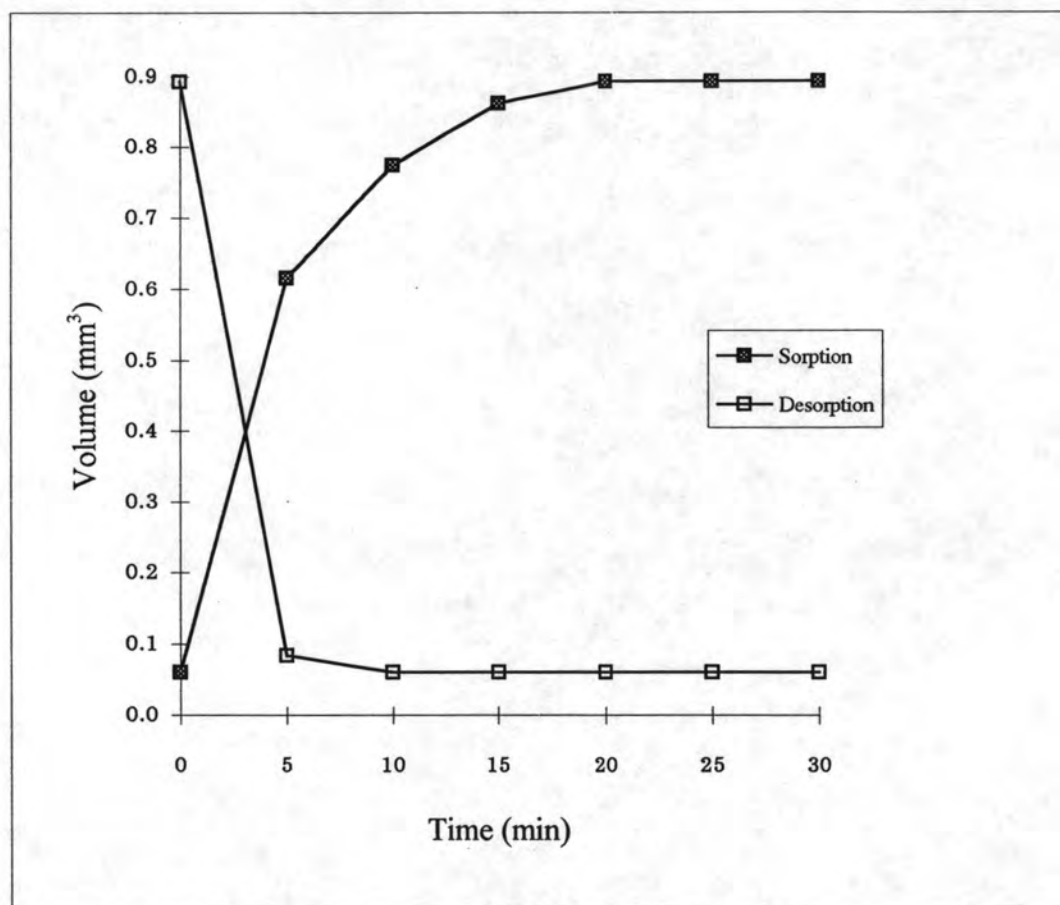


Figure B-18 Variation of bead volume with time: seed bead (C-H3/N2)

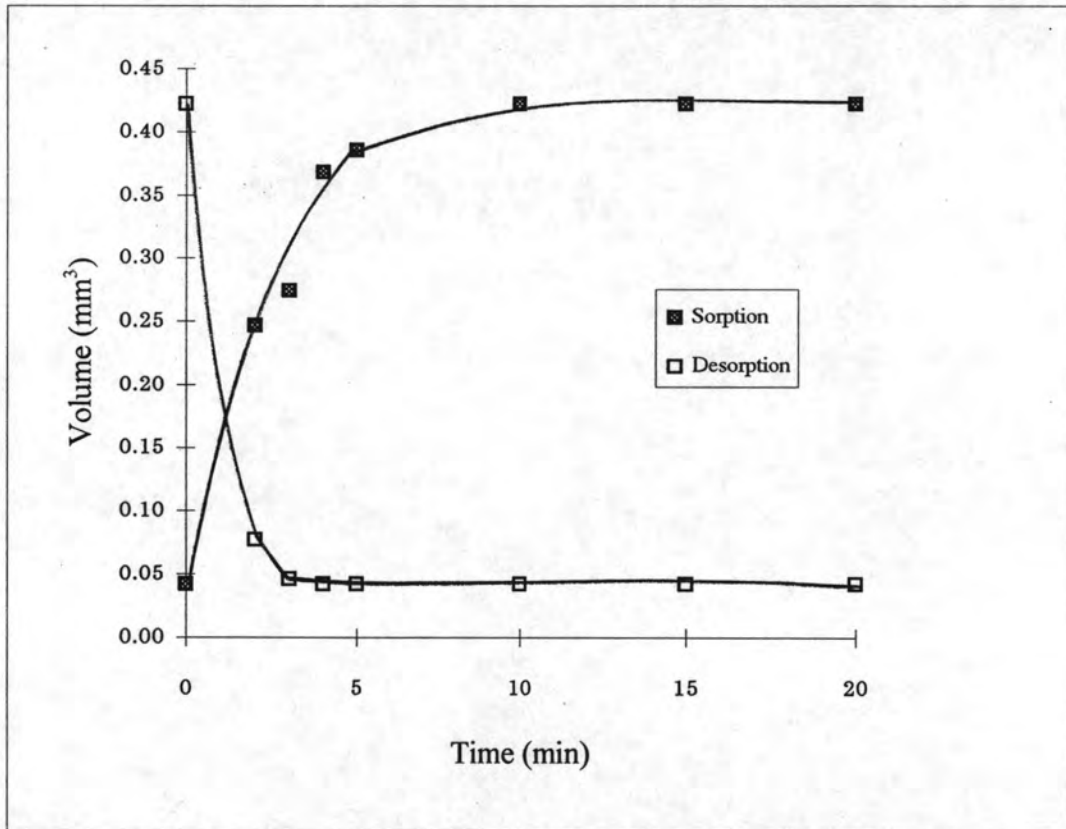
**Figure B-19** Sorption and desorption of toluene by seed bead (C-H1/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.4861	0.0602	-	1.00	1.1944	0.8926	-
5	1.0556	0.6161	0.1112	10.24	0.5417	0.0832	-0.1619
10	1.1389	0.7738	0.0315	12.86	0.4861	0.0602	-0.0046
15	1.1806	0.8619	0.0176	14.32	0.4861	0.0602	0.0000
20	1.1944	0.8926	0.0062	14.83	0.4861	0.0602	0.0000
25	1.1944	0.8926	0.0000	14.83	0.4861	0.0602	0.0000
30	1.1944	0.8926	0.0000	14.83	0.4861	0.0602	0.0000

**Figure B-19** Variation of bead volume with time: seed bead (C-H1/N3)

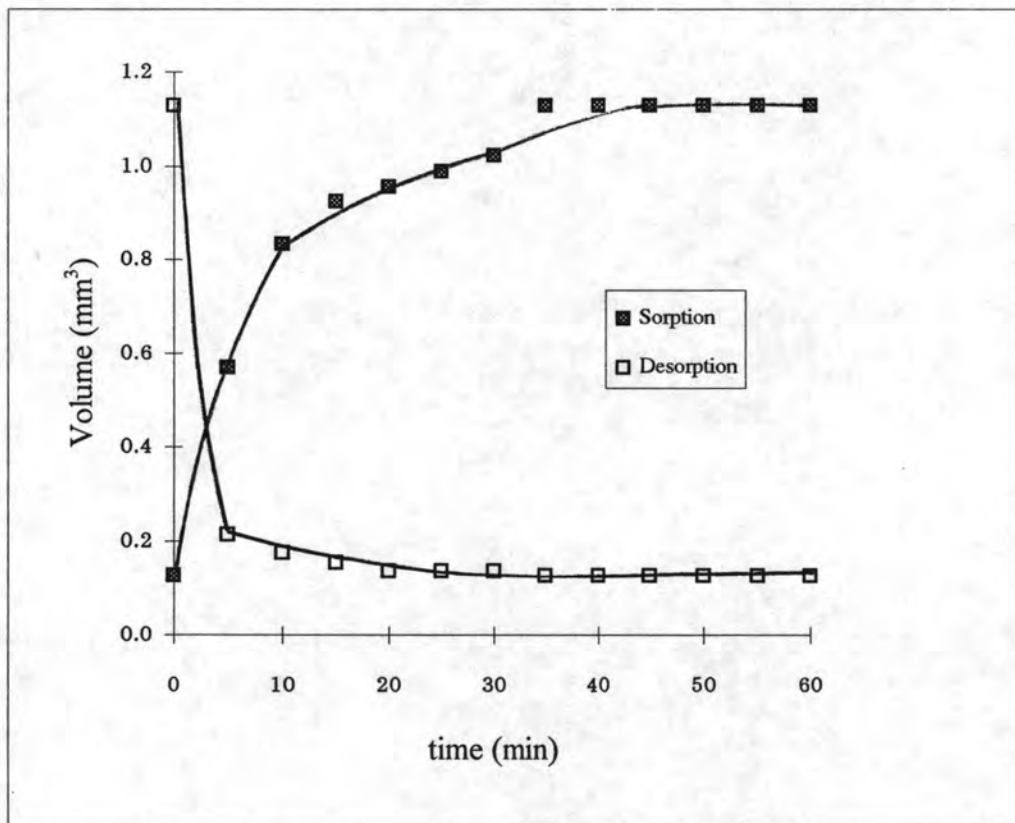
**Figure B-20** Sorption and desorption of toluene by seed bead (C-H2/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.4306	0.0418	-	1.00	0.9306	0.4221	-
2	0.7778	0.2465	0.1023	5.89	0.5278	0.0770	-0.1725
3	0.8056	0.2738	0.0274	6.55	0.4444	0.0460	-0.0310
4	0.8889	0.3679	0.0941	8.80	0.4306	0.0418	-0.0042
5	0.9028	0.3854	0.0175	9.22	0.4306	0.0418	0.0000
10	0.9306	0.4221	0.0073	10.10	0.4306	0.0418	0.0000
15	0.9306	0.4221	0.0000	10.10	0.4306	0.0418	0.0000
20	0.9306	0.4221	0.0000	10.10	0.4306	0.0418	0.0000

**Figure B-19** Variation of bead volume with time: seed bead (C-H2/N3)

**Figure B-21** Sorption and desorption of toluene by seed bead (C-H3/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	vol ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.6250	0.1279	-	1.00	1.2917	1.1289	-
5	1.0278	0.5687	0.0882	4.45	0.7417	0.2137	-0.1830
10	1.1667	0.8318	0.0526	6.50	0.6944	0.1754	-0.0077
15	1.2083	0.9241	0.0185	7.23	0.6667	0.1552	-0.0040
20	1.2222	0.9564	0.0064	7.48	0.6389	0.1366	-0.0037
25	1.2361	0.9893	0.0066	7.74	0.6389	0.1366	0.0000
30	1.2500	1.0231	0.0067	8.00	0.6389	0.1366	0.0000
35	1.2917	1.1289	0.0212	8.83	0.6250	0.1279	-0.0017
40	1.2917	1.1289	0.0000	8.83	0.6250	0.1279	0.0000
45	1.2917	1.1289	0.0000	8.83	0.6250	0.1279	0.0000
50	1.2917	1.1289	0.0000	8.83	0.6250	0.1279	0.0000
55	1.2917	1.1289	0.0000	8.83	0.6250	0.1279	0.0000
60	1.2917	1.1289	0.0000	8.83	0.6250	0.1279	0.0000



**Figure B-21** Variation of bead volume with time: seed bead (C-H3/N3)



Figure B-22 Sorption and desorption of toluene by large bead (S-T0/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.4583	1.6246	-	1.00	2.4861	8.0489	-
5	1.8750	3.4528	0.3657	2.13	1.9583	3.9340	-0.8230
10	2.0000	4.1905	0.1475	2.58	1.7528	2.8207	-0.2227
15	2.0694	4.6423	0.0904	2.86	1.6250	2.2477	-0.1146
20	2.2083	5.6411	0.1998	3.47	1.5833	2.0792	-0.0337
25	2.2500	5.9665	0.0651	3.67	1.5556	1.9716	-0.0215
30	2.2500	5.9665	0.0000	3.67	1.5139	1.8174	-0.0308
35	2.2639	6.0777	0.0222	3.74	1.5139	1.8174	0.0000
40	2.3056	6.4195	0.0684	3.95	1.5139	1.8174	0.0000
45	2.3750	7.0172	0.1195	4.32	1.5000	1.7679	-0.0099
50	2.3889	7.1410	0.0248	4.40	1.4861	1.7192	-0.0097
55	2.3889	7.1410	0.0000	4.40	1.4722	1.6715	-0.0095
60	2.4028	7.2663	0.0251	4.47	1.4584	1.6246	-0.0094
90	2.4861	8.0489	0.0261	4.95	1.4584	1.6246	0.0000
120	2.4861	8.0489	0.0000	4.95	1.4584	1.6246	0.0000

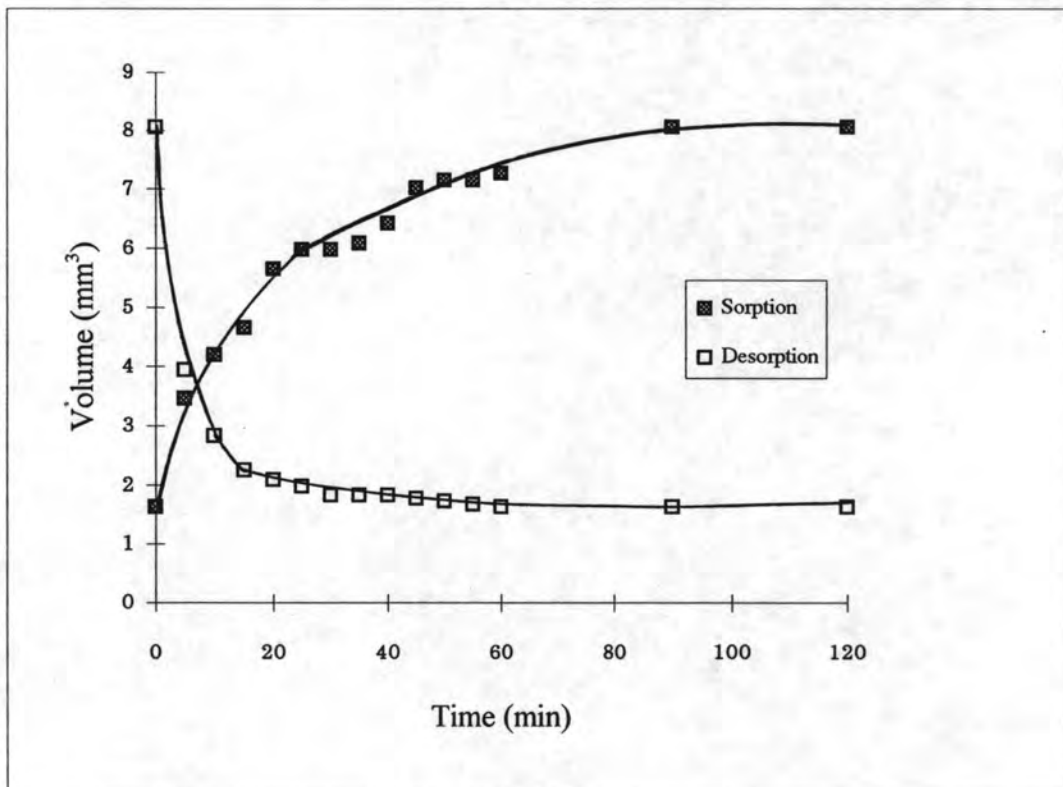


Figure B-22 Variation of bead volume with time: large bead (S-T0/N1)

Figure B-23 Sorption and desorption of toluene by large bead (S-T1/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.0972	0.6919	-	1.00	2.1667	5.3278	-
5	1.7222	2.6757	0.3968	3.87	1.6111	2.1905	-0.6275
10	1.9444	3.8509	0.2350	5.57	1.3056	1.1656	-0.2050
15	2.0417	4.4579	0.1214	6.44	1.2361	0.9893	-0.0353
20	2.0694	4.6423	0.0369	6.71	1.1944	0.8926	-0.0193
25	2.1111	4.9284	0.0572	7.12	1.1806	0.8619	-0.0062
30	2.1389	5.1255	0.0394	7.41	1.1806	0.8619	0.0000
35	2.1528	5.2260	0.0201	7.55	1.1667	0.8318	-0.0060
40	2.1667	5.3278	0.0204	7.70	1.1528	0.8024	-0.0059
45	2.1667	5.3278	0.0000	7.70	1.1528	0.8024	0.0000
50	2.1667	5.3278	0.0000	7.70	1.1389	0.7738	-0.0057
55	2.1667	5.3278	0.0000	7.70	1.1389	0.7738	0.0000
60	2.1667	5.3278	0.0000	7.70	1.1250	0.7458	-0.0056
90	2.1667	5.3278	0.0000	7.70	1.1111	0.7185	-0.0009
120	2.1667	5.3278	0.0000	7.70	1.0972	0.6919	-0.0009

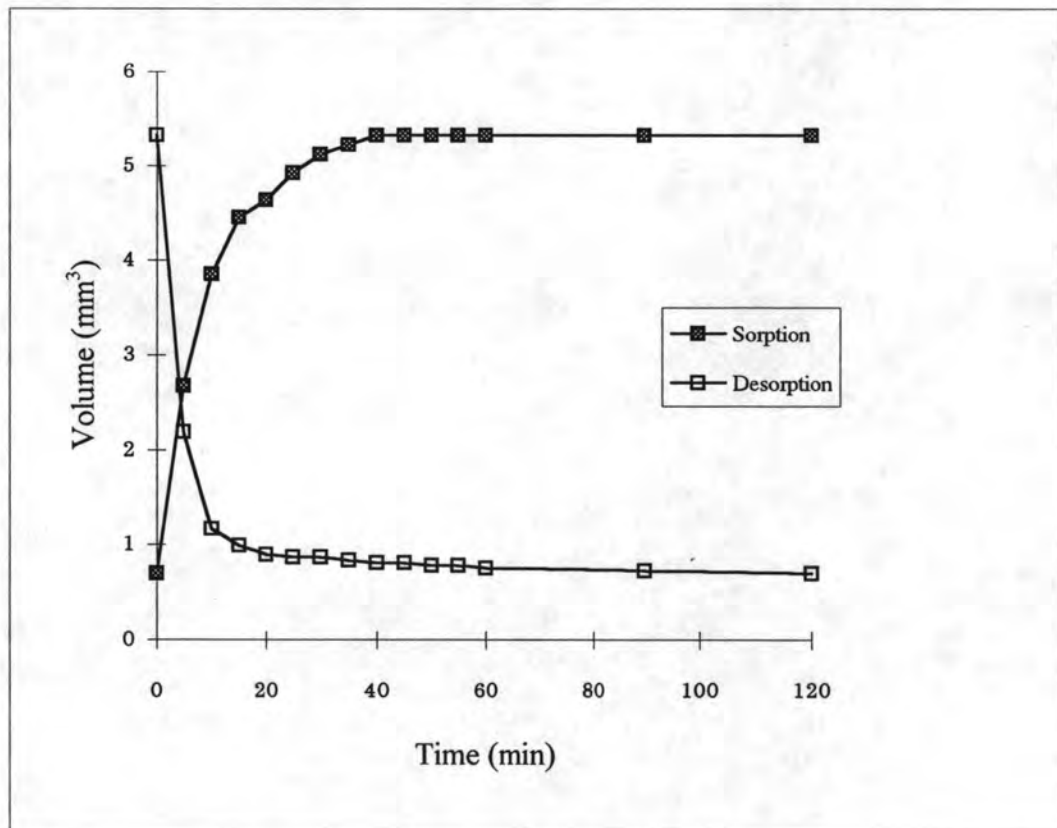


Figure B-23 Variation of bead volume with time: large bead (S-T1/N1)

Figure B-24 Sorption and desorption of toluene by large bead (S-T2/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.4444	1.5786	-	1.00	3.0139	14.3402	-
5	2.0694	4.6423	0.6127	2.94	2.7222	10.5668	-0.7547
10	2.2778	6.1903	0.3096	3.92	2.5000	8.1845	-0.4765
15	2.3889	7.1410	0.1902	4.52	2.0833	4.7364	-0.6896
20	2.5833	9.0305	0.3779	5.72	1.8333	3.2277	-0.3017
25	2.6528	9.7786	0.1496	6.19	1.7083	2.6115	-0.1232
30	2.7083	10.4059	0.1255	6.59	1.6528	2.3649	-0.0493
35	2.7778	11.2271	0.1642	7.11	1.6528	2.3649	0.0000
40	2.7917	11.3963	0.0339	7.22	1.5833	2.0792	-0.0572
45	2.8889	12.6289	0.2465	8.00	1.5694	2.0249	-0.0108
50	2.9028	12.8120	0.0366	8.12	1.5417	1.9193	-0.0211
55	2.9306	13.1833	0.0743	8.35	1.5139	1.8174	-0.0204
60	2.9306	13.1833	0.0000	8.35	1.5139	1.8174	0.0000
90	3.0139	14.3402	0.0386	9.08	1.4861	1.7192	-0.0033
120	3.0139	14.3402	0.0000	9.08	1.4583	1.6246	-0.0032
150	3.0139	14.3402	0.0000	9.08	1.4444	1.5786	-0.0015
180	3.0139	14.3402	0.0000	9.08	1.4444	1.5786	0.0000

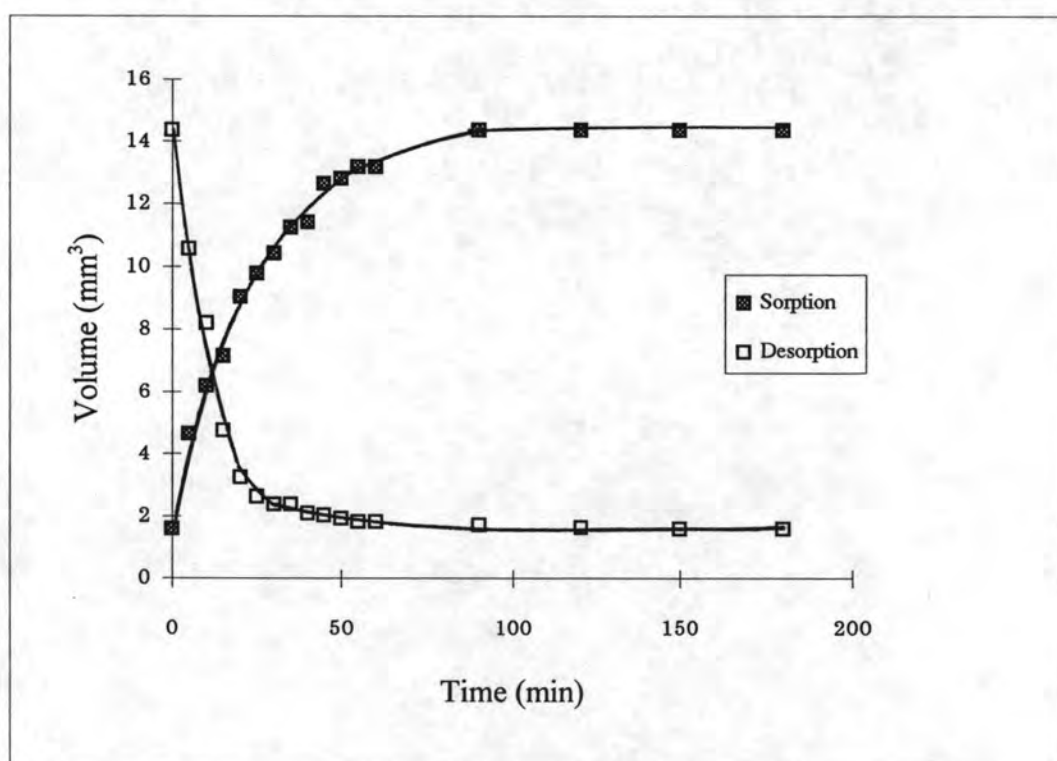


Figure B-24 Variation of bead volume with time: large bead (S-T2/N1)

Figure B-25 Sorption and desorption of toluene by large bead (S-T3/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.0139	0.5459	-	1.00	2.1528	5.2260	-
5	1.6250	2.2477	0.3403	4.12	1.6528	2.3649	-0.5722
10	1.8750	3.4528	0.2410	6.32	1.2361	0.9893	-0.2751
15	2.0139	4.2784	0.1651	7.84	1.0972	0.6919	-0.0595
20	2.0833	4.7364	0.0916	8.68	1.0694	0.6407	-0.0102
25	2.0833	4.7364	0.0000	8.68	1.0417	0.5921	-0.0097
30	2.0972	4.8318	0.0191	8.85	1.0417	0.5921	0.0000
35	2.1111	4.9284	0.0193	9.03	1.0278	0.5687	-0.0047
40	2.1111	4.9284	0.0000	9.03	1.0139	0.5459	-0.0045
45	2.1250	5.0263	0.0196	9.21	1.0139	0.5459	0.0000
50	2.1389	5.1255	0.0198	9.39	1.0139	0.5459	0.0000
55	2.1528	5.2260	0.0201	9.57	1.0139	0.5459	0.0000
60	2.1528	5.2260	0.0000	9.57	1.0139	0.5459	0.0000
90	2.1528	5.2260	0.0000	9.57	1.0139	0.5459	0.0000

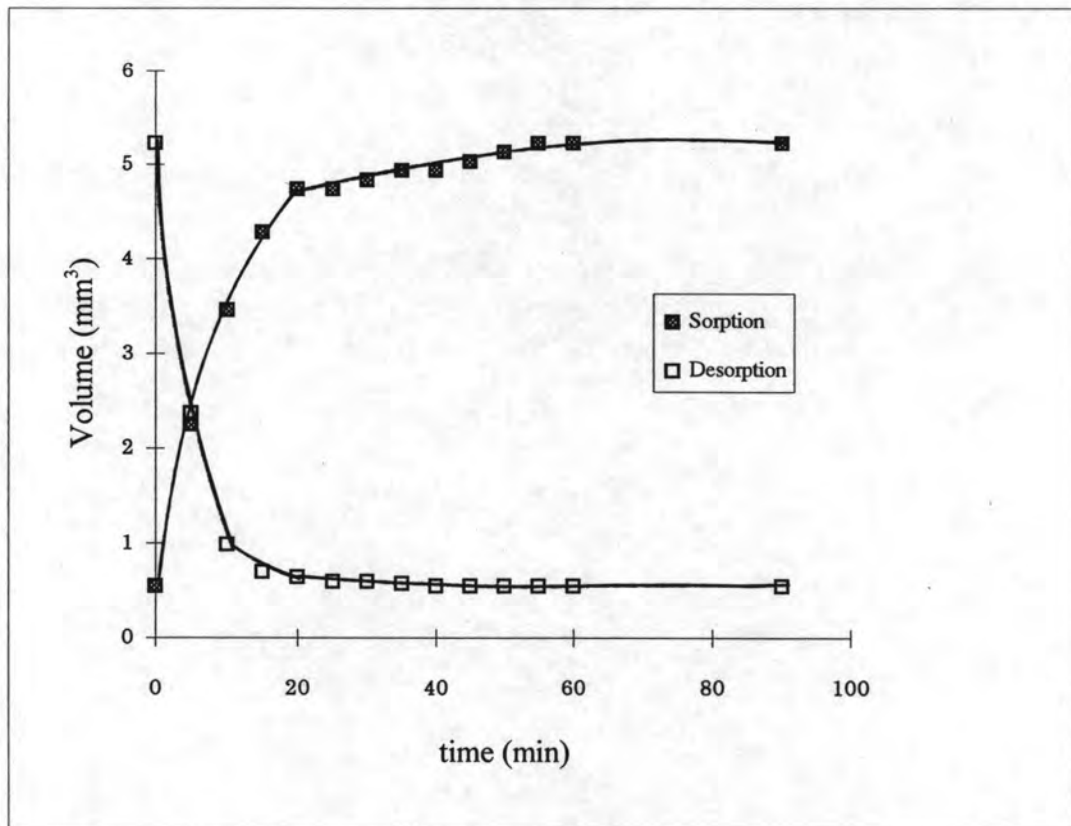


Figure B-25 Variation of bead volume with time: large bead (S-T3/N1)

Figure B-26 Sorption and desorption of toluene by large bead (S-T0/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.4583	1.6246	-	1.00	2.4722	7.9147	-
5	1.9167	3.6882	0.4127	2.27	2.2361	5.8567	-0.4116
10	2.0556	4.5495	0.1723	2.80	1.9444	3.8509	-0.4012
15	2.2500	5.9665	0.2834	3.67	1.7361	2.7410	-0.2220
20	2.3472	6.7738	0.1615	4.17	1.6250	2.2477	-0.0987
25	2.4167	7.3931	0.1238	4.55	1.5694	2.0249	-0.0446
30	2.4306	7.5213	0.0256	4.63	1.5416	1.9192	-0.0211
35	2.4583	7.7820	0.0522	4.79	1.5139	1.8174	-0.0204
40	2.4722	7.9147	0.0265	4.87	1.5139	1.8174	0.0000
45	2.4722	7.9147	0.0000	4.87	1.5000	1.7679	-0.0099
50	2.4722	7.9147	0.0000	4.87	1.4861	1.7192	-0.0097
55	2.4722	7.9147	0.0000	4.87	1.4861	1.7192	0.0000
60	2.4722	7.9147	0.0000	4.87	1.4722	1.6714	-0.0096
90	2.4722	7.9147	0.0000	4.87	1.4583	1.6246	-0.0016
120	2.4722	7.9147	0.0000	4.87	1.4583	1.6246	0.0000

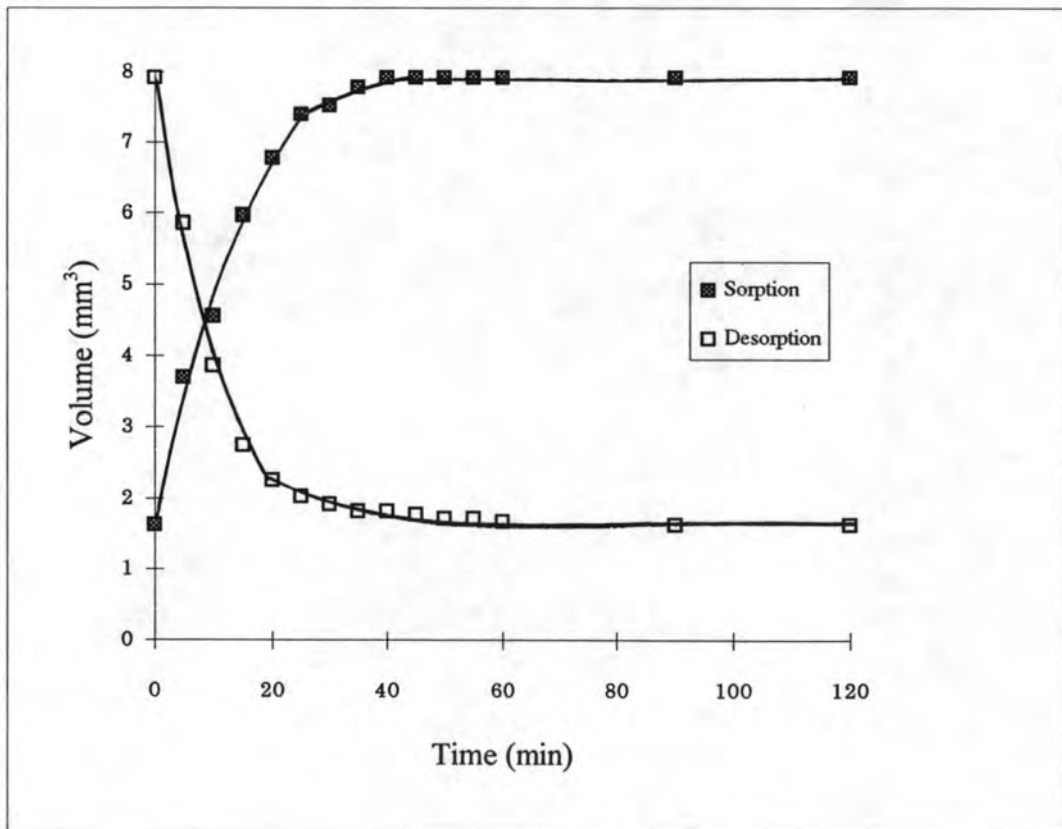


Figure B-26 Variation of bead volume with time: large bead (S-T0/N2)



Figure B-27 Sorption and desorption of toluene by large bead (S-T1/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.3889	1.4034	-	1.00	2.5417	8.6006	-
5	1.9306	3.7690	0.4731	2.69	2.1250	5.0263	-0.7149
10	2.0833	4.7364	0.1935	3.37	1.7778	2.9431	-0.4166
15	2.2083	5.6411	0.1809	4.02	1.6667	2.4251	-0.1036
20	2.3194	6.5362	0.1790	4.66	1.5833	2.0792	-0.0692
25	2.4028	7.2663	0.1460	5.18	1.5556	1.9717	-0.0215
30	2.4167	7.3931	0.0253	5.27	1.5278	1.8679	-0.0208
35	2.4444	7.6509	0.0516	5.45	1.5000	1.7679	-0.0200
40	2.4583	7.7820	0.0262	5.55	1.4861	1.7192	-0.0097
45	2.4722	7.9147	0.0265	5.64	1.4861	1.7192	0.0000
50	2.4722	7.9147	0.0000	5.64	1.4722	1.6714	-0.0096
55	2.4861	8.0489	0.0268	5.74	1.4583	1.6246	-0.0094
60	2.4861	8.0489	0.0000	5.74	1.4444	1.5786	-0.0092
90	2.5417	8.6006	0.0184	6.13	1.4167	1.4893	-0.0030
120	2.5417	8.6006	0.0000	6.13	1.3889	1.4034	-0.0029
150	2.5417	8.6006	0.0000	6.13	1.3889	1.4034	0.0000

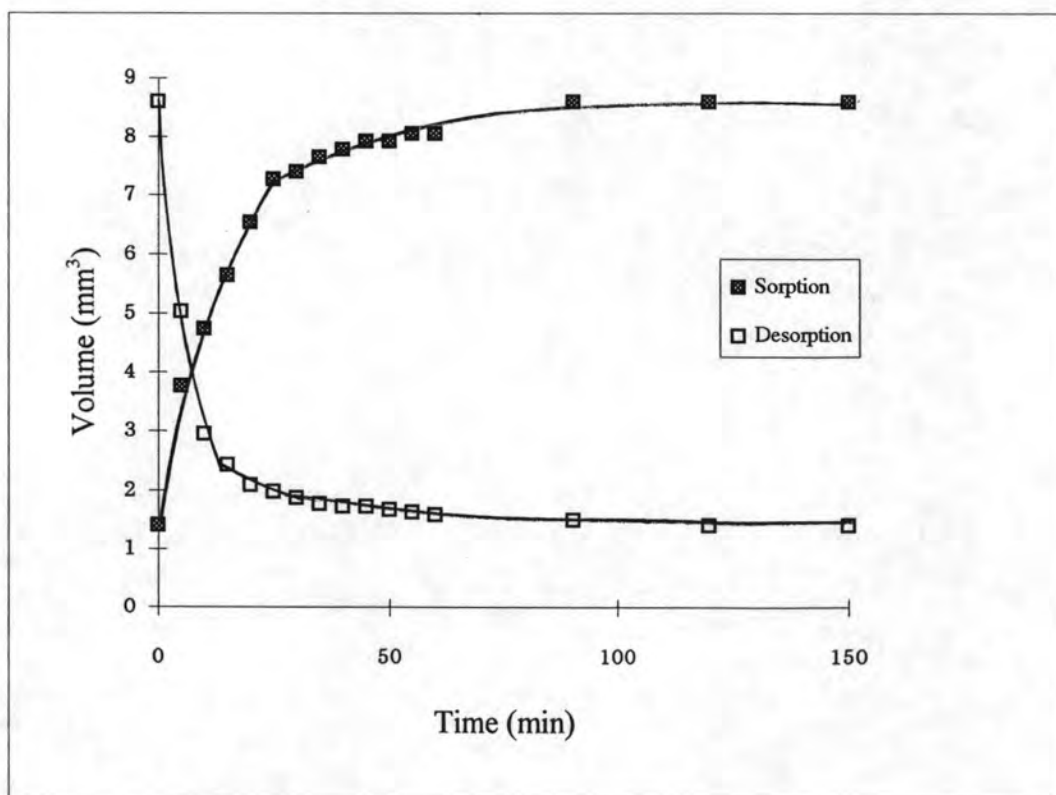


Figure B-27 Variation of bead volume with time: large bead (S-T1/N2)

Figure B-28 Sorption and desorption of toluene by large bead (S-T2/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.9583	0.4610	-	1.00	1.8194	3.1549	-
5	1.4861	1.7192	0.2516	3.73	1.2500	1.0231	-0.4264
10	1.6667	2.4251	0.1412	5.26	1.0972	0.6919	-0.0662
15	1.7500	2.8073	0.0764	6.09	1.0417	0.5921	-0.0200
20	1.7778	2.9431	0.0272	6.38	1.0278	0.5687	-0.0047
25	1.7917	3.0126	0.0139	6.53	1.0139	0.5459	-0.0045
30	1.8194	3.1549	0.0285	6.84	1.0139	0.5459	0.0000
35	1.8194	3.1549	0.0000	6.84	1.0000	0.5238	-0.0044
40	1.8194	3.1549	0.0000	6.84	1.0000	0.5238	0.0000
45	1.8194	3.1549	0.0000	6.84	0.9861	0.5023	-0.0043
50	1.8194	3.1549	0.0000	6.84	0.9861	0.5023	0.0000
55	1.8194	3.1549	0.0000	6.84	0.9722	0.4814	-0.0042
60	1.8194	3.1549	0.0000	6.84	0.9722	0.4814	0.0000
90	1.8194	3.1549	0.0000	6.84	0.9583	0.4610	-0.0007
120	1.8194	3.1549	0.0000	6.84	0.9583	0.4610	0.0000

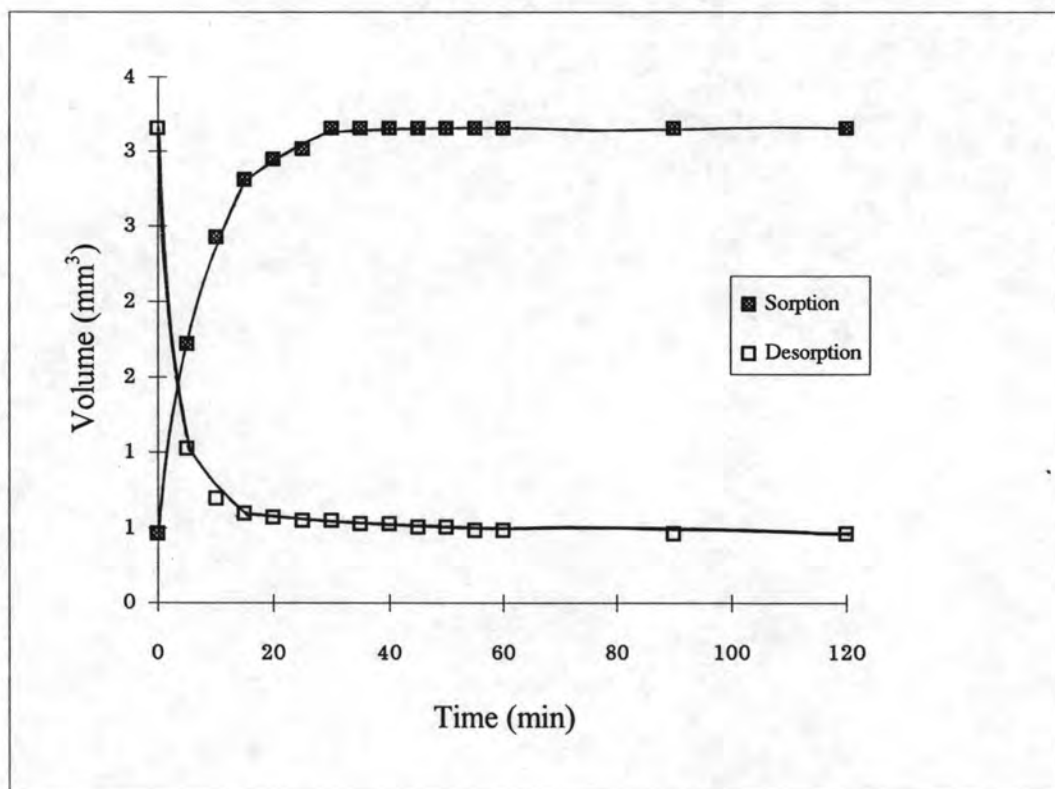


Figure B-28 Variation of bead volume with time: large bead (S-T2/N2)

Figure B-29 Sorption and desorption of toluene by large bead (S-T3/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.9028	0.3854	-	1.00	1.8056	3.0833	-
5	1.4583	1.6246	0.2478	4.22	1.1806	0.8619	-0.4443
10	1.6667	2.4251	0.1601	6.29	1.0139	0.5459	-0.0632
15	1.7500	2.8073	0.0764	7.28	0.9861	0.5023	-0.0087
20	1.7778	2.9431	0.0272	7.64	0.9722	0.4814	-0.0042
25	1.7917	3.0126	0.0139	7.82	0.9583	0.4610	-0.0041
30	1.8056	3.0833	0.0141	8.00	0.9444	0.4413	-0.0040
35	1.8056	3.0833	0.0000	8.00	0.9306	0.4221	-0.0038
40	1.8056	3.0833	0.0000	8.00	0.9306	0.4221	0.0000
45	1.8056	3.0833	0.0000	8.00	0.9306	0.4221	0.0000
50	1.8056	3.0833	0.0000	8.00	0.9306	0.4221	0.0000
55	1.8056	3.0833	0.0000	8.00	0.9167	0.4035	-0.0037
60	1.8056	3.0833	0.0000	8.00	0.9167	0.4035	0.0000
90	1.8056	3.0833	0.0000	8.00	0.9167	0.4035	0.0000
120	1.8056	3.0833	0.0000	8.00	0.9028	0.3854	-0.0036
150	1.8056	3.0833	0.0000	8.00	0.9028	0.3854	0.0000

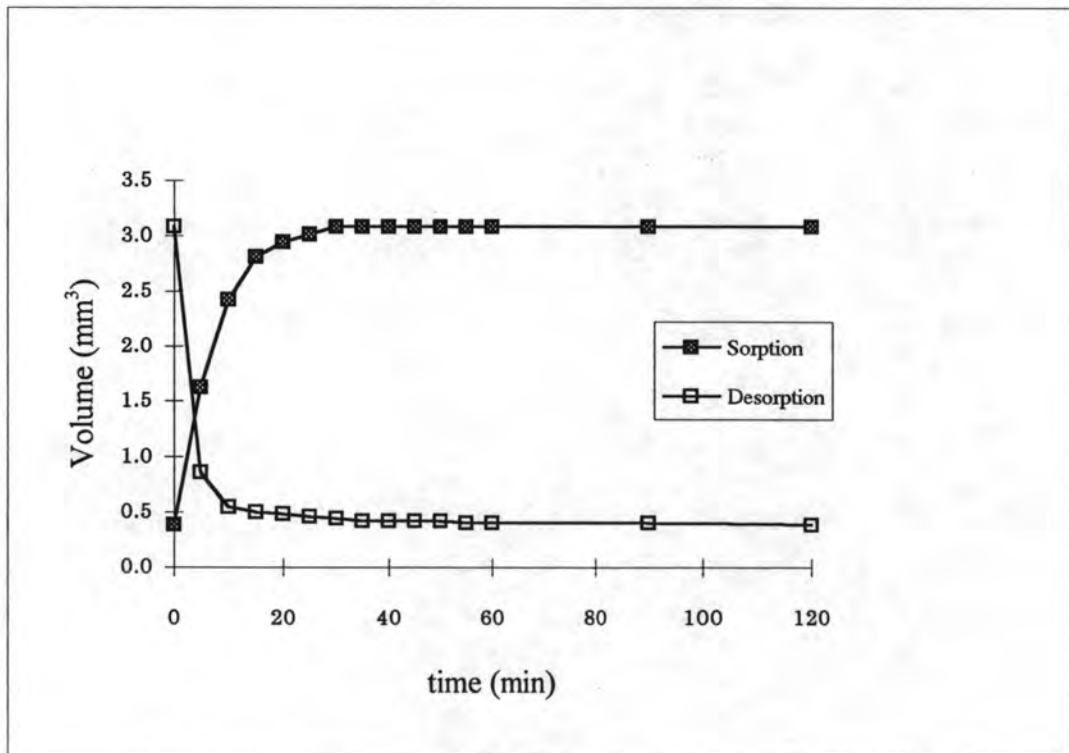
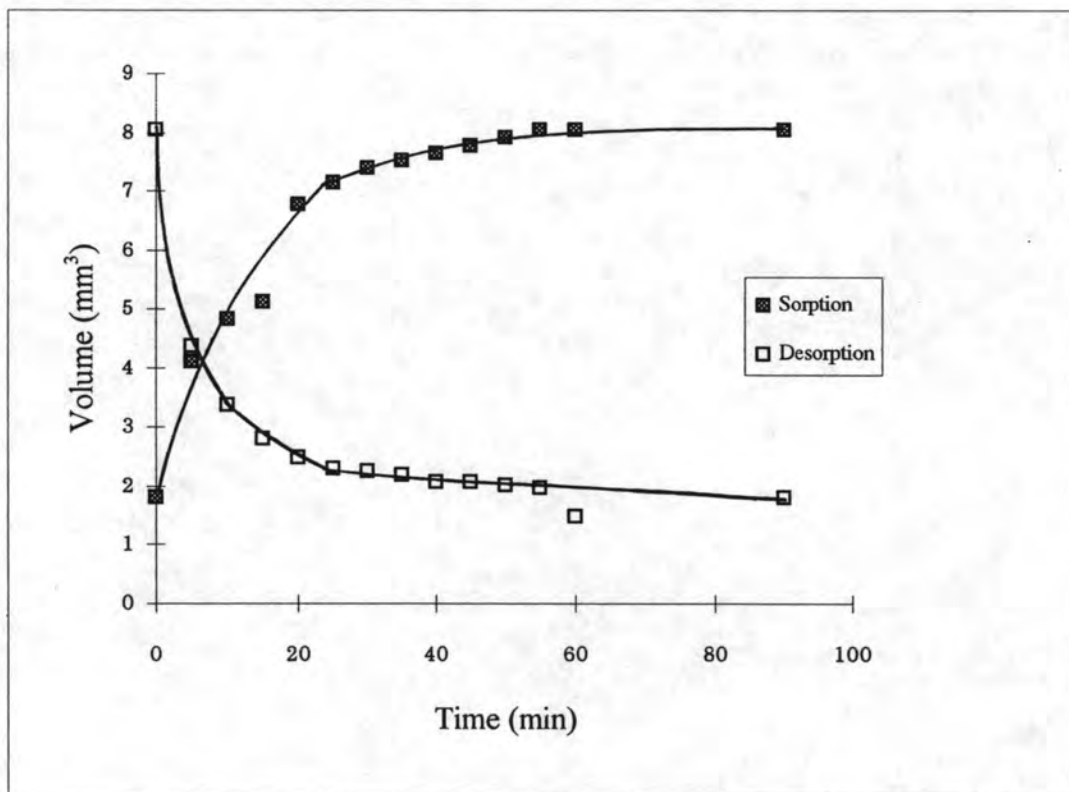


Figure B-29 Variation of bead volume with time: large bead (S-T3/N2)

**Figure B-30** Sorption and desorption of toluene by large bead (S-T0/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.5139	1.8174	-	1.00	2.4861	8.0489	-
5	1.9861	4.1038	0.4573	2.26	2.0278	4.3675	-0.7363
10	2.0972	4.8318	0.1456	2.66	1.8611	3.3767	-0.1982
15	2.1389	5.1255	0.0588	2.82	1.7500	2.8073	-0.1139
20	2.3472	6.7738	0.3297	3.73	1.6806	2.4862	-0.0642
25	2.3889	7.1410	0.0734	3.93	1.6389	2.3058	-0.0361
30	2.4167	7.3931	0.0504	4.07	1.6278	2.2592	-0.0093
35	2.4306	7.5213	0.0256	4.14	1.6111	2.1905	-0.0137
40	2.4444	7.6509	0.0259	4.21	1.5833	2.0792	-0.0223
45	2.4583	7.7820	0.0262	4.28	1.5833	2.0792	0.0000
50	2.4722	7.9147	0.0265	4.35	1.5694	2.0249	-0.0108
55	2.4861	8.0489	0.0268	4.43	1.5555	1.9716	-0.0107
60	2.4861	8.0489	0.0000	4.43	1.4167	1.4893	-0.0964
90	2.4861	8.0489	0.0000	4.43	1.5139	1.8174	0.0109



**Figure B-30** Variation of bead volume with time: large bead (S-T0/N3)

Figure B-31 Sorption and desorption of toluene by large bead (S-T1/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.1250	0.7458	-	1.00	1.9028	3.6086	-
5	1.4722	1.6714	0.1851	2.24	1.6250	2.2477	-0.2722
10	1.6389	2.3058	0.1269	3.09	1.3750	1.3617	-0.1772
15	1.7500	2.8073	0.1003	3.76	1.3194	1.2032	-0.0317
20	1.8056	3.0833	0.0552	4.13	1.3056	1.1656	-0.0075
25	1.8472	3.3016	0.0437	4.43	1.2778	1.0928	-0.0146
30	1.8611	3.3767	0.0150	4.53	1.2639	1.0576	-0.0071
35	1.8611	3.3767	0.0000	4.53	1.2639	1.0576	0.0000
40	1.8750	3.4528	0.0152	4.63	1.2500	1.0231	-0.0069
45	1.8889	3.5302	0.0155	4.73	1.2361	0.9893	-0.0067
50	1.8889	3.5302	0.0000	4.73	1.2111	0.9305	-0.0118
55	1.8889	3.5302	0.0000	4.73	1.1806	0.8619	-0.0137
60	1.8889	3.5302	0.0000	4.73	1.1667	0.8318	-0.0060
90	1.9028	3.6086	0.0026	4.84	1.1486	0.7938	-0.0013
120	1.9028	3.6086	0.0000	4.84	1.1250	0.7458	-0.0016
150	1.9028	3.6086	0.0000	4.84	1.1250	0.7458	0.0000

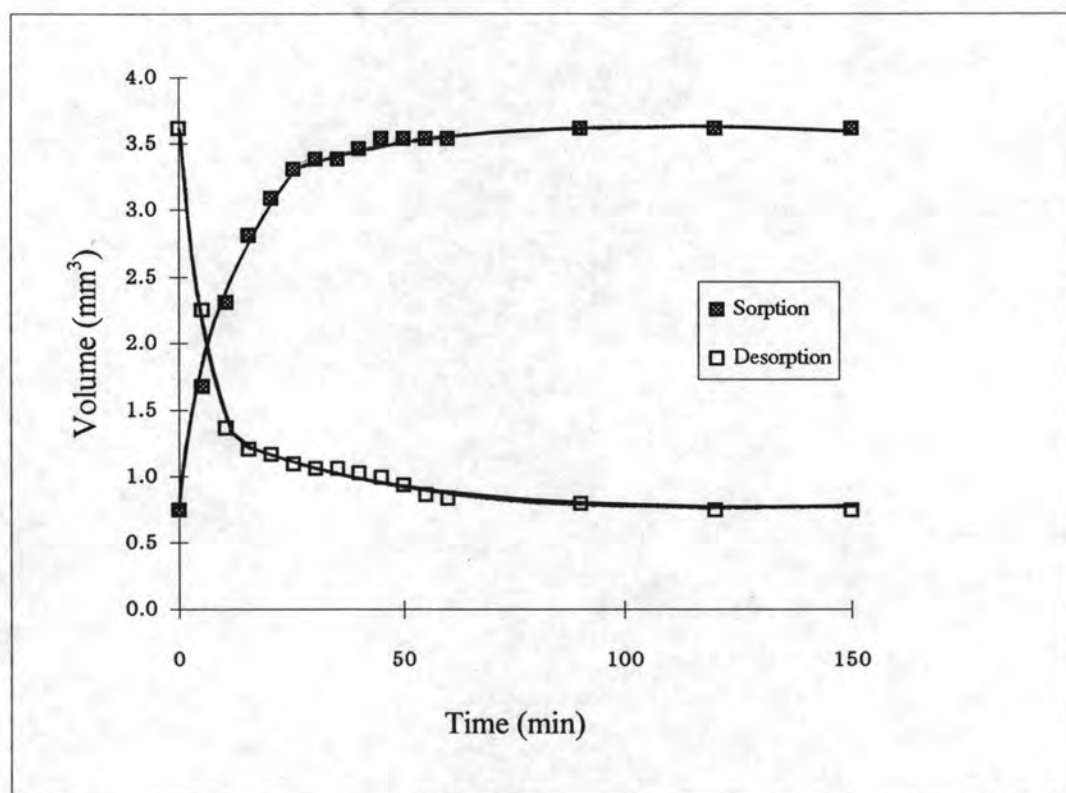


Figure B-31 Variation of bead volume with time: large bead (S-T1/N3)



Figure B-32 Sorption and desorption of toluene by large bead (S-T2/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.1389	0.7738	-	1.00	2.0278	4.3675	-
5	1.6389	2.3058	0.3064	2.98	1.6806	2.4862	-0.3763
10	1.7500	2.8073	0.1003	3.63	1.3333	1.2416	-0.2489
15	1.8750	3.4528	0.1291	4.46	1.2500	1.0231	-0.0437
20	1.9583	3.9340	0.0962	5.08	1.1944	0.8926	-0.0261
25	1.9722	4.0183	0.0169	5.19	1.1667	0.8318	-0.0122
30	2.0278	4.3675	0.0699	5.64	1.1667	0.8318	0.0000
35	2.0278	4.3675	0.0000	5.64	1.1528	0.8024	-0.0059
40	2.0278	4.3675	0.0000	5.64	1.1528	0.8024	0.0000
45	2.0278	4.3675	0.0000	5.64	1.1528	0.8024	0.0000
50	2.0278	4.3675	0.0000	5.64	1.1389	0.7738	-0.0057
55	2.0278	4.3675	0.0000	5.64	1.1389	0.7738	0.0000
60	2.0278	4.3675	0.0000	5.64	1.1389	0.7738	0.0000

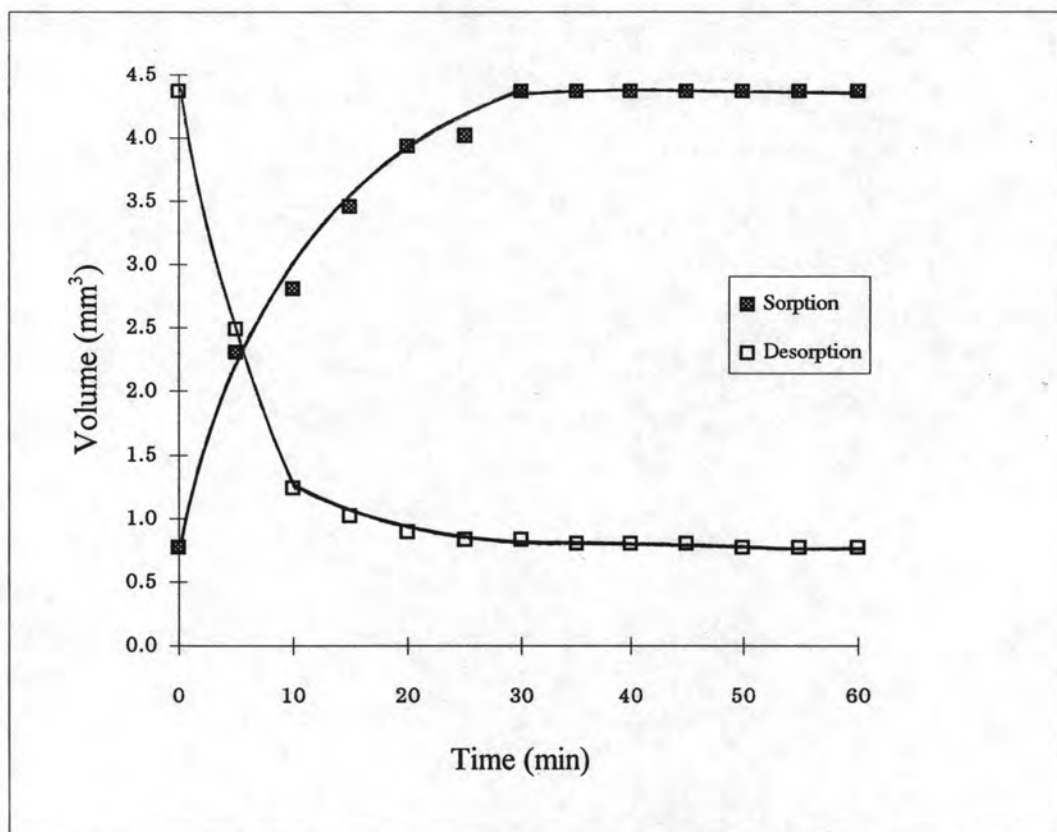


Figure B-32 Variation of bead volume with time: large bead (S-T2/N3)

Figure B-33 Sorption and desorption of toluene by large bead (S-T3/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.5278	1.8679	-	1.00	2.8750	12.4476	-
5	2.1389	5.1255	0.6515	2.74	2.5417	8.6006	-0.7694
10	2.3333	6.6543	0.3058	3.56	2.2639	6.0777	-0.5046
15	2.3740	7.0083	0.0708	3.75	1.9722	4.0183	-0.4119
20	2.5417	8.6006	0.3185	4.60	1.8333	3.2277	-0.1581
25	2.6528	9.7786	0.2356	5.24	1.7222	2.6757	-0.1104
30	2.7222	10.5668	0.1576	5.66	1.6528	2.3649	-0.0622
35	2.7500	10.8936	0.0654	5.83	1.6389	2.3058	-0.0118
40	2.8000	11.4987	0.1210	6.16	1.6111	2.1905	-0.0231
45	2.8333	11.9142	0.0831	6.38	1.5972	2.1344	-0.0112
50	2.8333	11.9142	0.0000	6.38	1.5833	2.0792	-0.0110
55	2.8333	11.9142	0.0000	6.38	1.5694	2.0249	-0.0108
60	2.8472	12.0903	0.0352	6.47	1.5417	1.9193	-0.0211
90	2.8611	12.2681	0.0059	6.57	1.5278	1.8679	-0.0103
120	2.8750	12.4476	0.0060	6.66	1.5278	1.8680	0.0000
150	2.8750	12.4476	0.0000	6.66	1.5278	1.8680	0.0000

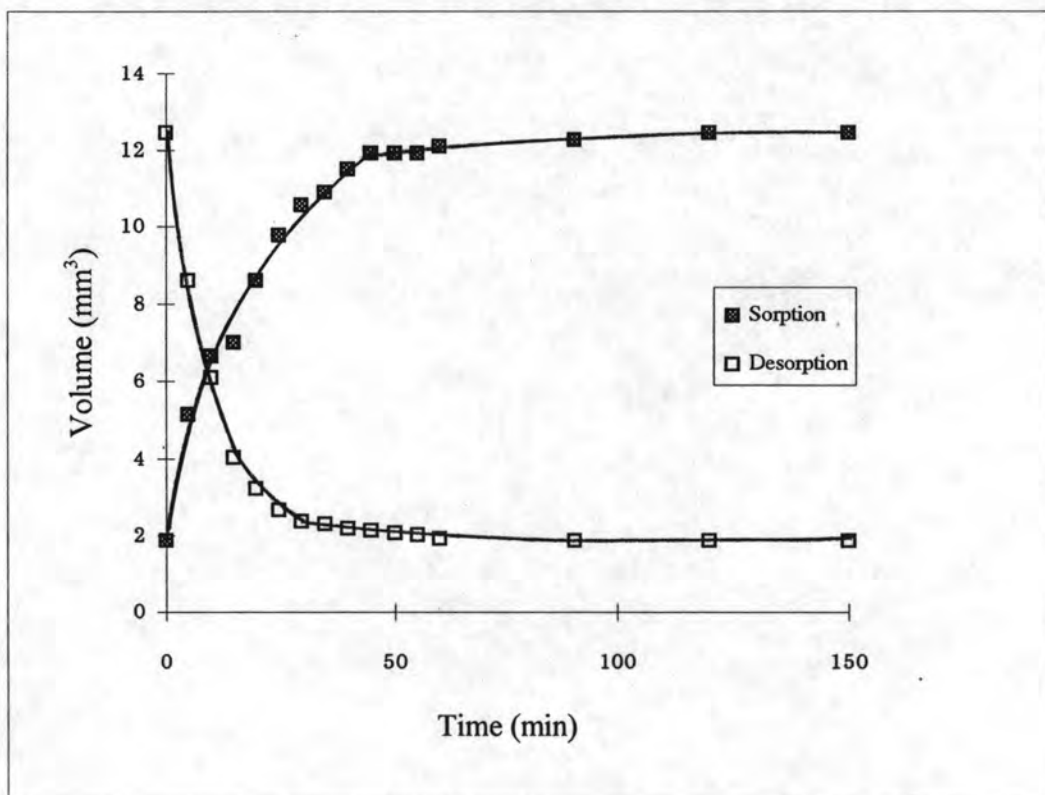


Figure B-33 Variation of bead volume with time: large bead (S-T3/N3)

Figure B-34 Sorption and desorption of toluene by large bead (S-H1/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.8194	0.2882	-	1.00	1.6806	2.4862	-
5	1.3889	1.4034	0.2230	4.87	1.0972	0.6919	-0.3589
10	1.5556	1.9717	0.1137	6.84	0.9306	0.4221	-0.0540
15	1.5722	2.0357	0.0128	7.06	0.8889	0.3679	-0.0108
20	1.5972	2.1344	0.0197	7.41	0.8750	0.3509	-0.0034
25	1.6111	2.1905	0.0112	7.60	0.8611	0.3345	-0.0033
30	1.6389	2.3058	0.0231	8.00	0.8611	0.3345	0.0000
35	1.6389	2.3058	0.0000	8.00	0.8611	0.3345	0.0000
40	1.6389	2.3058	0.0000	8.00	0.8472	0.3185	-0.0032
45	1.6528	2.3649	0.0118	8.21	0.8472	0.3185	0.0000
50	1.6528	2.3649	0.0000	8.21	0.8472	0.3185	0.0000
55	1.6667	2.4251	0.0120	8.41	0.8333	0.3031	-0.0031
60	1.6806	2.4862	0.0122	8.63	0.8333	0.3031	0.0000
90	1.6806	2.4862	0.0000	8.63	0.8194	0.2882	-0.0005
120	1.6806	2.4862	0.0000	8.63	0.8194	0.2882	0.0000

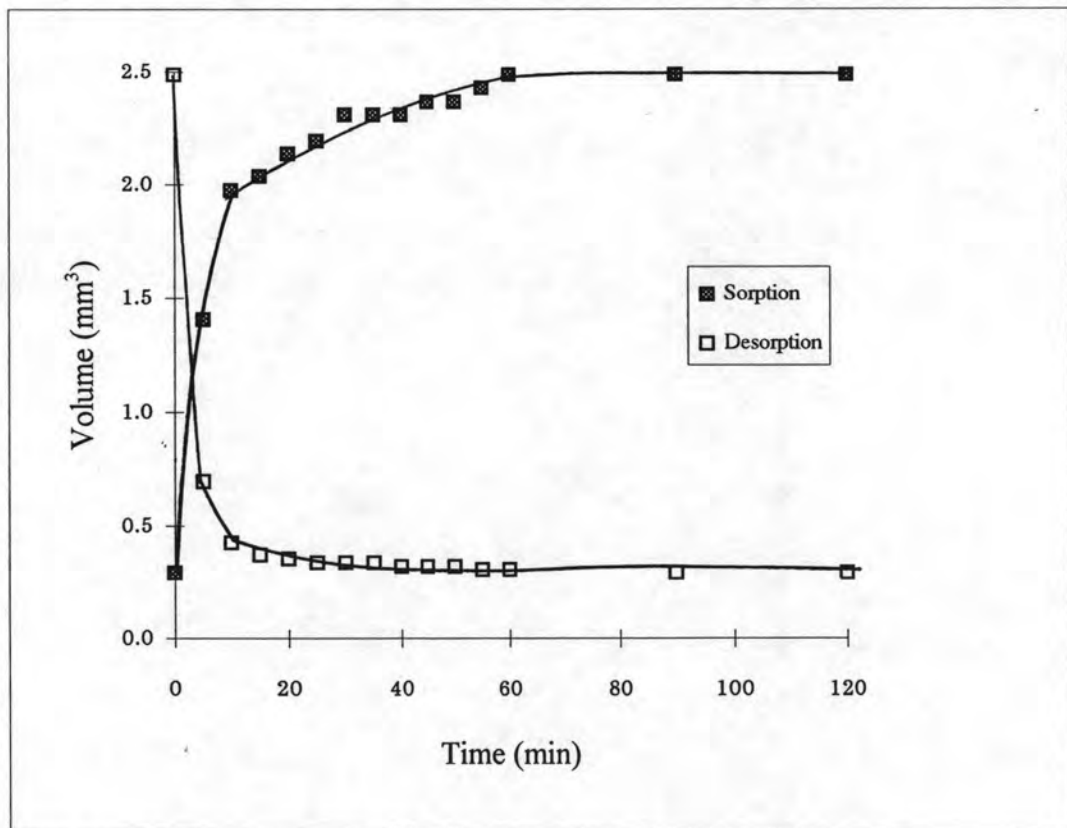


Figure B-34 Variation of bead volume with time: large bead (S-H1/N1)

Figure B-35 Sorption and desorption of toluene by large bead (S-H2/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.0694	0.6407	-	1.00	2.1528	5.2260	-
5	1.6944	2.5483	0.3815	3.98	1.7083	2.6115	-0.5229
10	1.8472	3.3016	0.1507	5.15	1.2917	1.1288	-0.2965
15	1.9861	4.1038	0.1604	6.41	1.1806	0.8619	-0.0534
20	2.0417	4.4579	0.0708	6.96	1.1250	0.7458	-0.0232
25	2.0556	4.5495	0.0183	7.10	1.1111	0.7185	-0.0055
30	2.0833	4.7364	0.0374	7.39	1.0973	0.6921	-0.0053
35	2.1111	4.9284	0.0384	7.69	1.0833	0.6660	-0.0052
40	2.1250	5.0263	0.0196	7.85	1.0694	0.6407	-0.0051
45	2.1250	5.0263	0.0000	7.85	1.0694	0.6407	0.0000
50	2.1528	5.2260	0.0399	8.16	1.0694	0.6407	0.0000
55	2.1528	5.2260	0.0000	8.16	1.0694	0.6407	0.0000
60	2.1528	5.2260	0.0000	8.16	1.0694	0.6407	0.0000

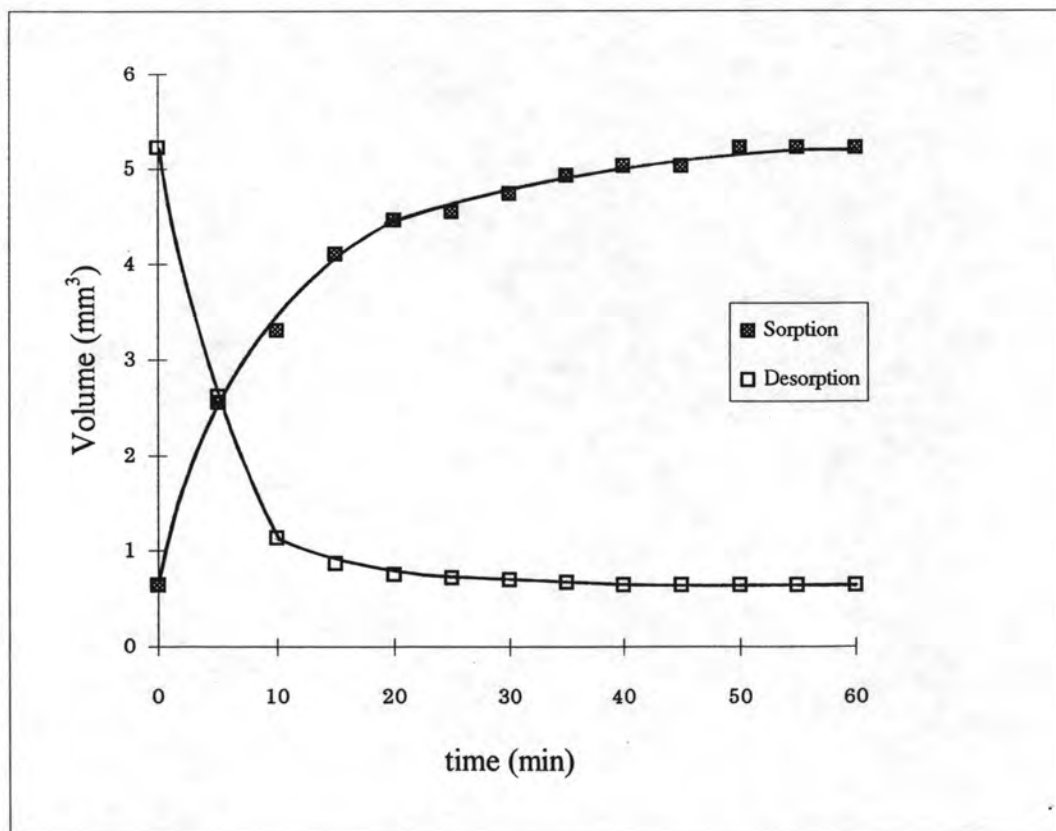


Figure B-35 Variation of bead volume with time: large bead (S-H2/N1)

Figure B-36 Sorption and desorption of toluene by large bead (S-H3/N1)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.1250	0.7458	-	1.00	1.8056	3.0833	-
5	1.5139	1.8174	0.2143	2.44	1.4167	1.4893	-0.3188
10	1.6528	2.3649	0.1095	3.17	1.3056	1.1656	-0.0647
15	1.7361	2.7410	0.0752	3.68	1.2500	1.0231	-0.0285
20	1.7917	3.0126	0.0543	4.04	1.2222	0.9564	-0.0133
25	1.8056	3.0833	0.0141	4.13	1.2222	0.9564	0.0000
30	1.8056	3.0833	0.0000	4.13	1.2083	0.9241	-0.0064
35	1.8056	3.0833	0.0000	4.13	1.2083	0.9241	0.0000
40	1.8056	3.0833	0.0000	4.13	1.1944	0.8926	-0.0063
45	1.8056	3.0833	0.0000	4.13	1.1806	0.8619	-0.0062
50	1.8056	3.0833	0.0000	4.13	1.1806	0.8619	0.0000
55	1.8056	3.0833	0.0000	4.13	1.1667	0.8318	-0.0060
60	1.8056	3.0833	0.0000	4.13	1.1667	0.8318	0.0000
90	1.8056	3.0833	0.0000	4.13	1.1528	0.8024	-0.0010
120	1.8056	3.0833	0.0000	4.13	1.1389	0.7738	-0.0010
150	1.8056	3.0833	0.0000	4.13	1.1250	0.7458	-0.0009

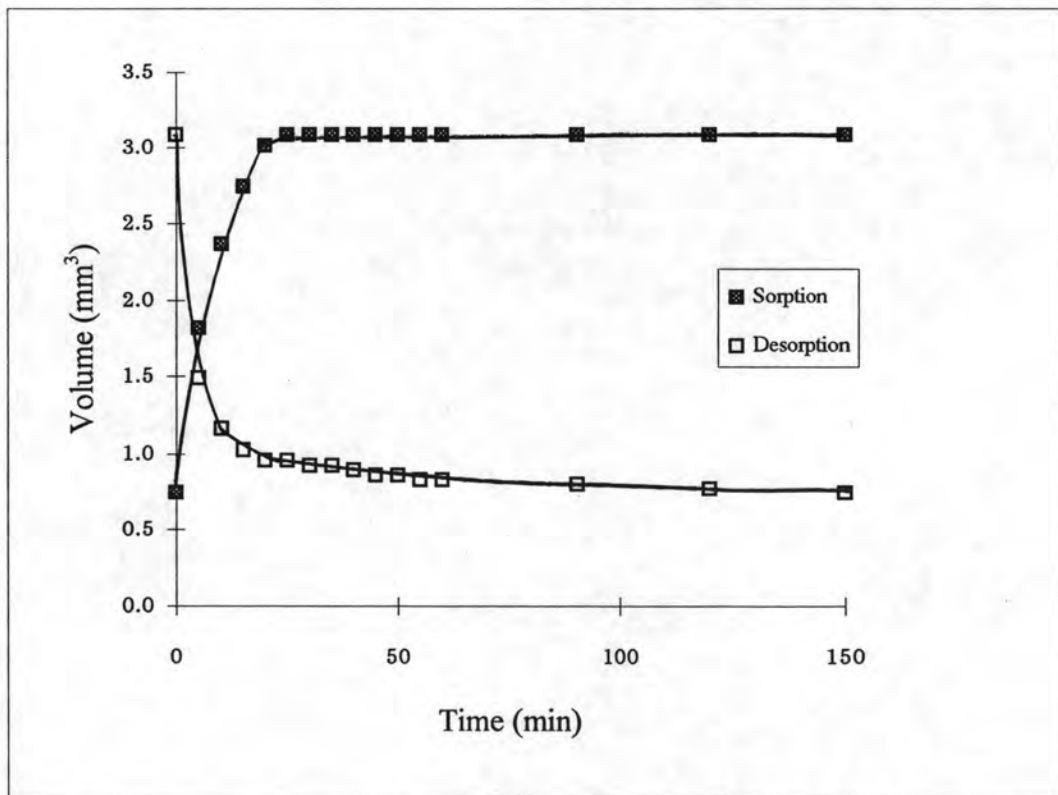


Figure B-36 Variation of bead volume with time: large bead (S-H3/N1)



Figure B-37 Sorption and desorption of toluene by large bead (S-H1/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.0833	0.6660	-	1.00	2.3750	7.0172	-
5	1.6944	2.5483	0.3765	3.83	1.9861	4.1038	-0.5827
10	1.9722	4.0183	0.2940	6.03	1.5694	2.0249	-0.4158
15	2.1111	4.9283	0.1820	7.40	1.2500	1.0231	-0.2004
20	2.1667	5.3278	0.0799	8.00	1.1944	0.8925	-0.0261
25	2.2194	5.7267	0.0798	8.60	1.1667	0.8318	-0.0121
30	2.2639	6.0777	0.0702	9.13	1.1389	0.7738	-0.0116
35	2.2917	6.3042	0.0453	9.47	1.1250	0.7458	-0.0056
40	2.3194	6.5362	0.0464	9.81	1.1250	0.7458	0.0000
45	2.3194	6.5362	0.0000	9.81	1.1250	0.7458	0.0000
50	2.3333	6.6543	0.0236	9.99	1.1250	0.7458	0.0000
55	2.3333	6.6543	0.0000	9.99	1.1111	0.7185	-0.0055
60	2.3611	6.8948	0.0481	10.35	1.0972	0.6919	-0.0053
90	2.3750	7.0172	0.0041	10.54	1.0833	0.6660	-0.0009
120	2.3750	7.0172	0.0000	10.54	1.0833	0.6660	0.0000

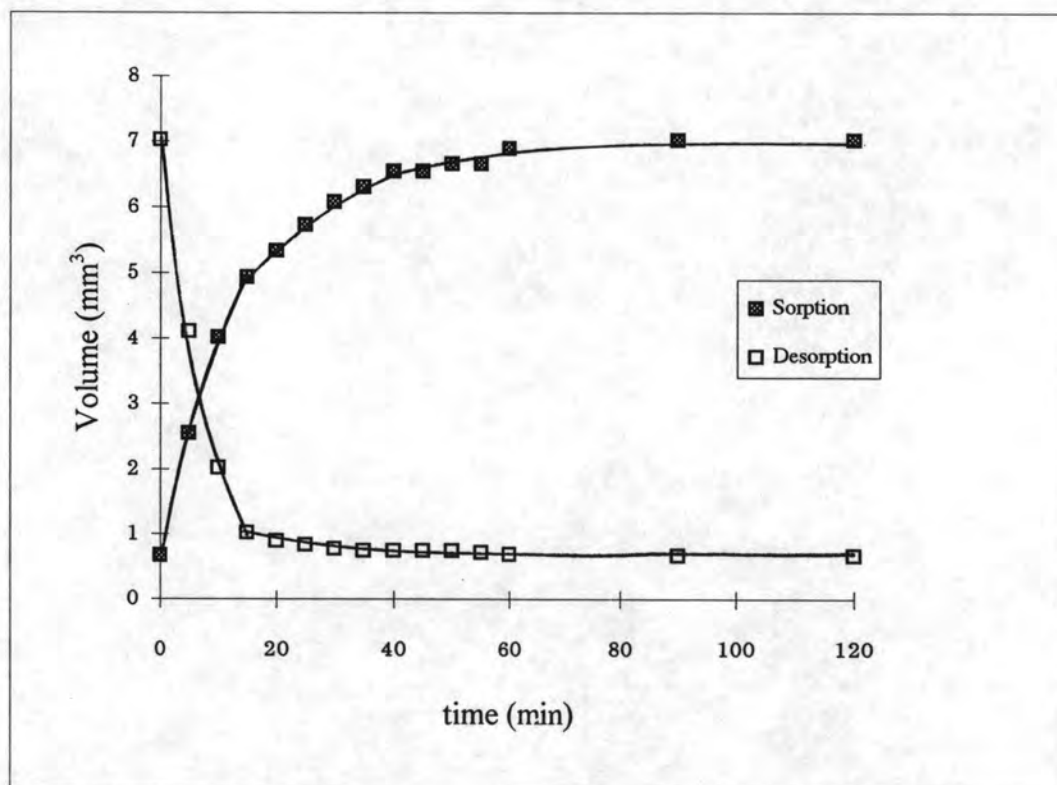


Figure B-37 Variation of bead volume with time: large bead (S-H1/N2)

Figure B-38 Sorption and desorption of toluene by large bead (S-H2/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.9722	0.4814	-	1.00	1.8472	3.3016	-
5	1.5278	1.8679	0.2773	3.88	1.3472	1.2808	-0.4042
10	1.6528	2.3649	0.0994	4.91	1.1806	0.8619	-0.0838
15	1.7639	2.8747	0.1019	5.97	1.1111	0.7185	-0.0287
20	1.7917	3.0126	0.0276	6.26	1.0942	0.6863	-0.0065
25	1.8056	3.0833	0.0141	6.41	1.0417	0.5921	-0.0188
30	1.8194	3.1549	0.0143	6.55	1.0278	0.5687	-0.0047
35	1.8194	3.1549	0.0000	6.55	1.0556	0.6161	0.0095
40	1.8333	3.2277	0.0146	6.71	1.0477	0.6023	-0.0027
45	1.8472	3.3016	0.0148	6.86	1.0278	0.5687	-0.0067
50	1.8472	3.3016	0.0000	6.86	1.0278	0.5687	0.0000
55	1.8472	3.3016	0.0000	6.86	1.0278	0.5687	0.0000
60	1.8472	3.3016	0.0000	6.86	1.0278	0.5687	0.0000
90	1.8472	3.3016	0.0000	6.86	1.0139	0.5459	-0.0008
120	1.8472	3.3016	0.0000	6.86	1.0000	0.5238	-0.0007
150	1.8472	3.3016	0.0000	6.86	0.9722	0.4813	-0.0014
180	1.8472	3.3016	0.0000	6.86	0.9722	0.4813	0.0000

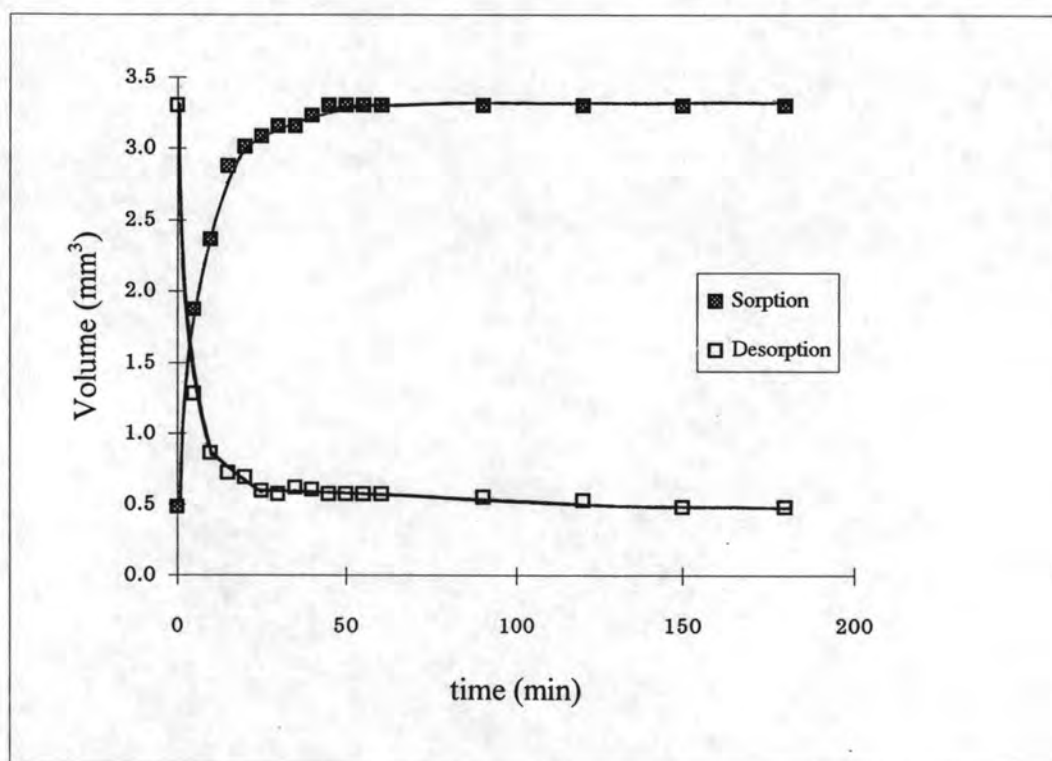


Figure B-38 Variation of bead volume with time: large bead (S-H2/N2)

Figure B-39 Sorption and desorption of toluene by large bead. (S-H3/N2)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.8750	0.3509	-	1.00	2.0417	4.4581	-
5	1.5694	2.0249	0.3348	5.77	1.7083	2.6115	-0.3693
10	1.7619	2.8649	0.1680	8.16	1.2083	0.9241	-0.3375
15	1.8611	3.3767	0.1024	9.62	0.9861	0.5023	-0.0844
20	1.9444	3.8509	0.0948	10.97	0.9306	0.4221	-0.0160
25	2.0000	4.1905	0.0679	11.94	0.9167	0.4035	-0.0037
30	2.0000	4.1905	0.0000	11.94	0.9028	0.3854	-0.0036
35	2.0139	4.2784	0.0176	12.19	0.8750	0.3509	-0.0069
40	2.0139	4.2784	0.0000	12.19	0.8750	0.3509	0.0000
45	2.0278	4.3675	0.0178	12.45	0.8750	0.3509	0.0000
50	2.0417	4.4579	0.0181	12.70	0.8750	0.3509	0.0000
55	2.0417	4.4579	0.0000	12.70	0.8750	0.3509	0.0000
60	2.0417	4.4579	0.0000	12.70	0.8750	0.3509	0.0000

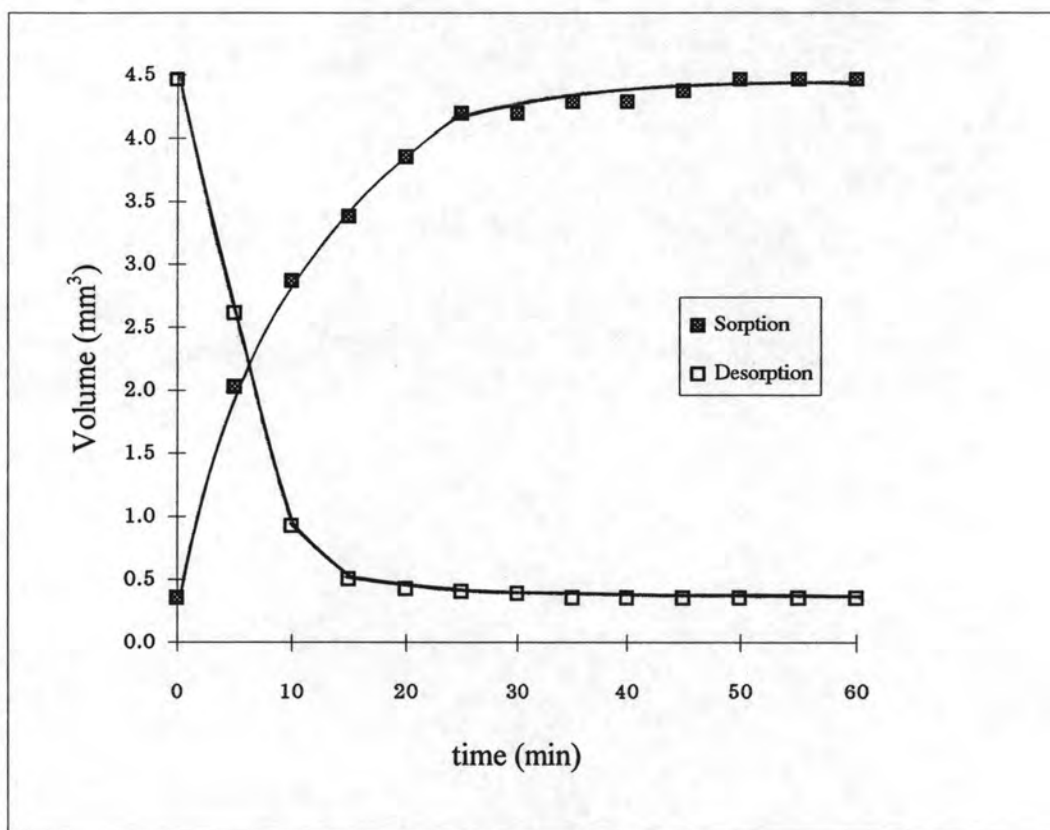


Figure B-39 Variation of bead volume with time: large bead (S-H3/N2)

Figure B-40 Sorption and desorption of toluene by large bead (S-H1/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.1528	0.8024	-	1.00	2.2500	5.9665	-
5	1.7639	2.8747	0.4144	3.58	1.9028	3.6086	-0.4716
10	1.9583	3.9340	0.2119	4.90	1.4861	1.7192	-0.3779
15	2.0139	4.2784	0.0689	5.33	1.3056	1.1656	-0.1107
20	2.0694	4.6423	0.0728	5.79	1.2500	1.0231	-0.0285
25	2.1250	5.0263	0.0768	6.26	1.2361	0.9893	-0.0067
30	2.1389	5.1255	0.0198	6.39	1.2222	0.9564	-0.0066
35	2.1806	5.4310	0.0611	6.77	1.1944	0.8926	-0.0127
40	2.1945	5.5354	0.0209	6.90	1.1806	0.8619	-0.0062
45	2.2083	5.6412	0.0212	7.03	1.1764	0.8528	-0.0018
50	2.2222	5.7483	0.0214	7.16	1.1667	0.8318	-0.0042
55	2.2361	5.8568	0.0217	7.30	1.1667	0.8318	0.0000
60	2.2361	5.8568	0.0000	7.30	1.1667	0.8318	0.0000
90	2.2361	5.8568	0.0000	7.30	1.1528	0.8024	-0.0010
120	2.2500	5.9668	0.0037	7.44	1.1528	0.8024	0.0000
150	2.2500	5.9668	0.0000	7.44	1.1528	0.8024	0.0000

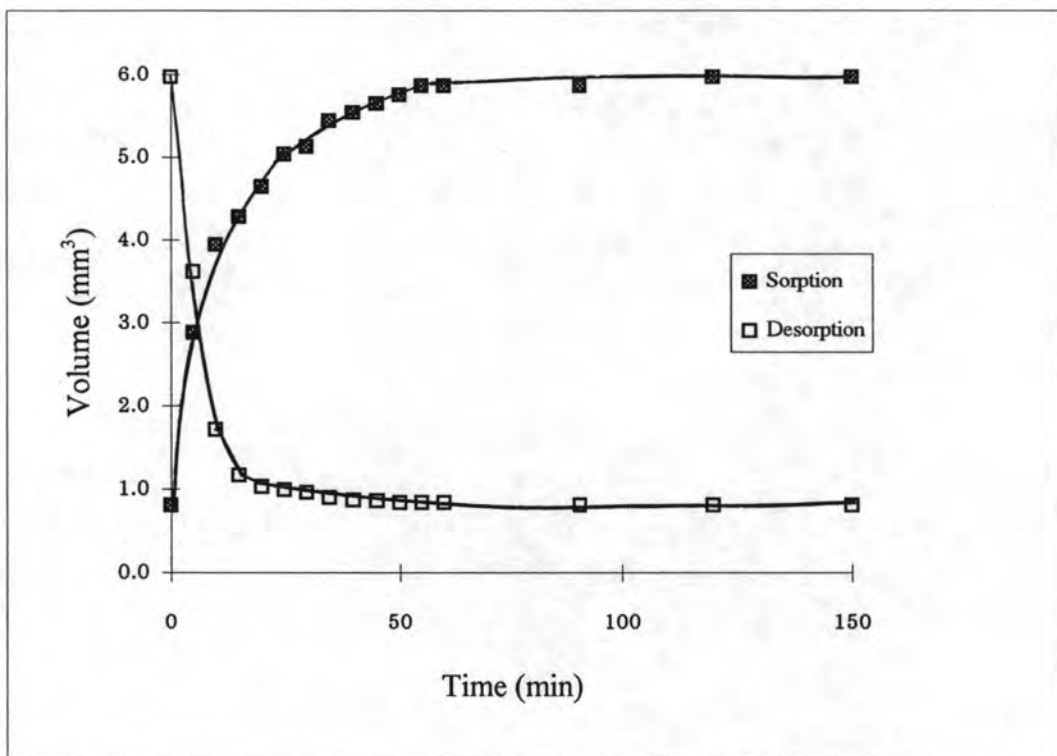


Figure B-40 Variation of bead volume with time: large bead (S-H1/N3)

Figure B-41 Sorption and desorption of toluene by large bead (S-H2/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	1.0833	0.6660	-	1.00	1.9306	3.7690	-
5	1.5833	2.0792	0.2826	3.12	1.4861	1.7192	-0.4100
10	1.7500	2.8073	0.1456	4.22	1.2778	1.0928	-0.1253
15	1.8472	3.3016	0.0989	4.96	1.2222	0.9564	-0.0273
20	1.8889	3.5302	0.0457	5.30	1.1944	0.8926	-0.0127
25	1.9167	3.6882	0.0316	5.54	1.1806	0.8619	-0.0062
30	1.9306	3.7690	0.0162	5.66	1.1667	0.8318	-0.0060
35	1.9306	3.7690	0.0000	5.66	1.1528	0.8024	-0.0059
40	1.9306	3.7690	0.0000	5.66	1.1528	0.8024	0.0000
45	1.9306	3.7690	0.0000	5.66	1.1389	0.7738	-0.0057
50	1.9306	3.7690	0.0000	5.66	1.1250	0.7458	-0.0056
55	1.9306	3.7690	0.0000	5.66	1.1250	0.7458	0.0000
60	1.9306	3.7690	0.0000	5.66	1.1111	0.7185	-0.0055
90	1.9306	3.7690	0.0000	5.66	1.0833	0.6660	-0.0018
120	1.9306	3.7690	0.0000	5.66	1.0833	0.6660	0.0000

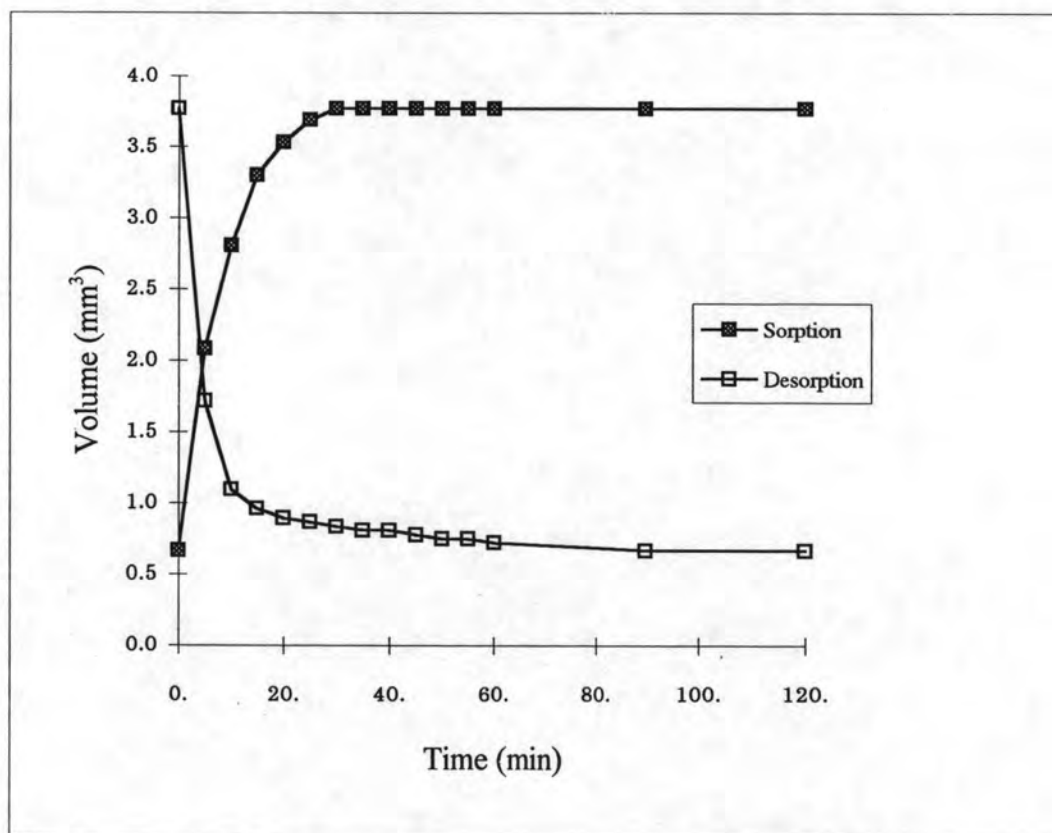


Figure B-41 Variation of bead volume with time: large bead (S-H2/N3)



Figure B-42 Sorption and desorption of toluene by large bead (S-H3/N3)

Sorption					Desorption		
Time (min)	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)	Vol. ratio	Bead dia. (mm)	Bead vol. (mm <sup>3</sup> )	$\Delta V/\Delta T$ (mm <sup>3</sup> /min)
0	0.9583	0.4610	-	1.00	1.6111	2.1905	-
5	1.3750	1.3617	0.1801	2.95	1.1944	0.8926	-0.2596
10	1.4722	1.6715	0.0619	3.63	1.0833	0.6660	-0.0453
15	1.5139	1.8174	0.0292	3.94	1.0556	0.6161	-0.0100
20	1.5556	1.9716	0.0308	4.28	1.0417	0.5921	-0.0048
25	1.5695	2.0250	0.0107	4.39	1.0278	0.5687	-0.0047
30	1.5695	2.0250	0.0000	4.39	1.0278	0.5687	0.0000
35	1.5695	2.0250	0.0000	4.39	1.0139	0.5459	-0.0045
40	1.5972	2.1344	0.0219	4.63	1.0139	0.5459	0.0000
45	1.5972	2.1344	0.0000	4.63	0.9861	0.5023	-0.0087
50	1.5972	2.1344	0.0000	4.63	0.9861	0.5023	0.0000
55	1.5972	2.1344	0.0000	4.63	0.9861	0.5023	0.0000
60	1.5972	2.1344	0.0000	4.63	0.9722	0.4814	-0.0042
90	1.6111	2.1905	0.0019	4.75	0.9583	0.4610	-0.0007
120	1.6111	2.1905	0.0000	4.75	0.9583	0.4610	0.0000

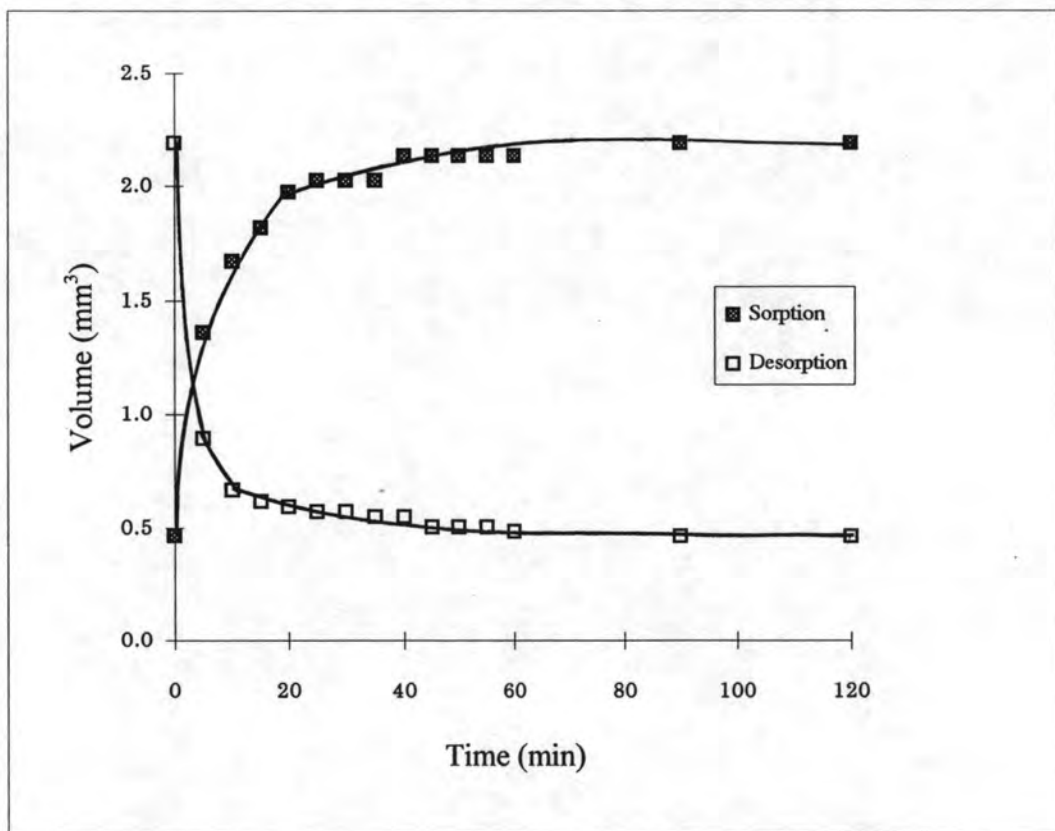


Figure B-42 Variation of bead volume with time: large bead (S-H3/N3)

## APPENDIX C

### The Calculation of the Diffusion Coefficient of the Imbiber Bead

The diffusion coefficient of the imbiber bead can be calculated from Eq. (2)

$$\tau = a^2 / D \quad (2)$$

where  $\tau$  is a characteristic swelling time

$a$  is the final radius of the fully swollen gel.

$D$  is the diffusion coefficient of the gel in the liquid.

From Eq. 3, The characteristic swelling time  $\tau$  can be obtained from the slope of the  $\ln (\Delta a_t / \Delta a_0)$  - time plot.

$$\ln (\Delta a_t / \Delta a_0) = \text{const.} \cdot -t / \tau \quad (3)$$

where  $\Delta a_t$  is the difference between the size at time  $t$  and that at saturation swelling

$\Delta a_0$  is the total change in radius throughout the entire swelling process

From the experiment, sample code S-T3/N3, the slope of the  $\ln (\Delta a_t / \Delta a_0)$  - time plot is -0.0855. Thus,

$$\tau = 11.7 \text{ min}$$

$$\begin{aligned} \text{Since } a &= 1.4375 \text{ mm, thus, } D = 0.177 \text{ mm}^2/\text{min} \\ &= 1.77 \times 10^{-3} \text{ cm}^2/\text{min} \end{aligned}$$

**Table C-1** Data for the calculation of the diffusion coefficient of the seed and large beads prepared by using toluene as diluent.

Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
C-T0/N1	0	0.375	-	-
	5	0.6806	0.3056	-0.3746
	10	0.7569	0.0764	-1.7609
	15	0.7917	0.0347	-2.5494
	20	0.7985	0.0068	-4.1744
	25	0.8056	0.007	-4.1431
C-T0/N3	0	0.375	-	-
	5	0.5972	0.2222	-0.5233
	10	0.6736	0.0764	-1.5911
	15	0.7083	0.0347	-2.3796
	20	0.7153	0.0069	-3.9889
	30	0.7431	0.0278	-2.6028
	50	0.75	0.007	-3.9882
C-T3/N3	0	0.2639	-	-
	5	0.5903	0.3264	-0.2607
	10	0.6528	0.0625	-1.914
	15	0.6597	0.0069	-4.1115
	20	0.6806	0.0208	-3.0122
	30	0.6875	0.0069	-4.1108
C-T3/N1	0	0.2778	-	-
	5	0.5278	0.25	-0.2662
	10	0.5694	0.0417	-2.5058
	15	0.5833	0.0319	-3.1569
	20	0.5903	0.0069	3.85
	25	0.5972	0.0069	3.85
	40	0.6041	0.0069	3.85

(continued)

Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
S-T0/N1	0	07291	-	-
	5	0.9375	0.2083	-0.9028
	10	1	0.0625	-2.1068
	15	1.0347	0.0347	-2.6946
	20	1.1042	0.0694	2.0015
	25	1.125	0.0208	3.2054
	35	1.132	0.0069	-4.304
	40	1.1528	0.0208	-3.2054
	45	1.1875	0.0347	-2.6946
	50	1.1944	0.0069	-4.304
	60	1.2014	0.0069	-4.304
	90	1.2431	0.0416	-2.5123
S-T0/N2	0	0.7291	-	-
	5	0.9583	0.229	-0.794
	10	1.0278	0.0694	-1.9879
	15	1.125	0.0972	-1.651
	20	1.1736	0.0486	-2.3446
	25	1.2083	0.03473	-2.6809
	30	1.2158	0.0069	-4.2903
	35	0.0139	0.0139	-3.5976
	40	0.0069	0.0069	-4.2904
	S-T0/N3	0	0.7569	-
5		0.9931	0.2361	-0.7222
10		1.0486	0.0555	-2.1691
15		1.0695	0.0209	-3.1491
20		1.1736	0.1042	-1.5406
25		1.1945	0.0209	-3.1491
30		1.2084	0.0139	-3.5545
35		1.2153	0.0069	-4.2477
40		1.2222	0.0069	-4.2549
45		1.2292	0.0069	-4.2477

(continued)

Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
S-T1/N1	0	0.5486	-	-
	5	0.8611	0.3125	-0.5372
	10	0.9722	0.1111	-1.5712
	15	1.0208	0.0486	-2.3978
	20	1.0347	0.0139	-3.6509
	25	1.0555	0.0208	-3.2451
	30	1.0694	0.0139	-3.6506
	35	1.0764	0.0069	-4.3437
	40	1.0833	0.0069	-4.3437
S-T1/N2	0	0.6944	-	-
	5	0.9653	0.2708	-0.7553
	10	1.0417	0.0764	-2.021
	15	1.1042	0.0625	-2.2216
	20	1.1597	0.0555	-2.3394
	25	1.2014	0.04167	-2.627
	30	1.2083	0.0069	-4.4188
	35	1.2222	0.0139	-3.726
	40	1.2292	0.0069	-4.4188
	55	1.2431	0.0069	-4.419
	90	1.2708	0.0278	-3.0325
S-T1/N3	0	0.5625	-	-
	5	0.73611	0.1736	-0.8065
	10	0.8195	0.0833	-1.5404
	15	0.875	0.0555	-1.9459
	20	0.9028	0.0278	-2.639
	25	0.9236	0.0208	-2.9269
	30	0.9305	0.0069	-4.0253
	40	0.9375	0.0069	-4.0253
	45	0.9445	0.0069	-4.0253
	90	0.9514	0.0069	-4.0253



(continued)

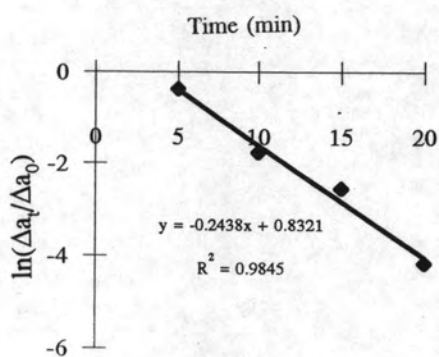
Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
S-T2/N1	0	0.7222	-	-
	5	1.0347	0.3125	-0.9207
	10	1.1389	0.1042	-2.0193
	15	1.1945	0.0555	-2.648
	20	1.2917	0.0972	-2.0884
	25	1.3264	0.0347	-3.1179
	30	1.3542	0.0278	-3.3412
	35	1.3889	0.0347	-3.1179
	40	1.3958	0.0069	-4.7273
	45	1.4445	0.04861	-2.7815
	50	1.4514	0.0069	-4.7273
	55	1.4653	0.0139	-4.0342
	90	1.5069	0.0417	-2.9357
S-T2/N2	0	0.4792	-	-
	5	0.7431	0.2639	-0.4895
	10	0.8333	0.0903	-1.5622
	15	0.875	0.0417	-2.3354
	20	0.8889	0.0139	-3.4339
	25	0.8958	0.0069	-4.1271
	30	0.9097	0.0139	-3.4343
S-T2/N3	0	0.5695	-	-
	5	0.8195	0.25	-0.5754
	10	0.875	0.0555	-2.0795
	15	0.9375	0.0625	-1.9617
	20	0.9792	0.0417	-2.3672
	25	0.9861	0.0069	-4.1588
	30	1.0139	0.0278	-2.7725

(continued)

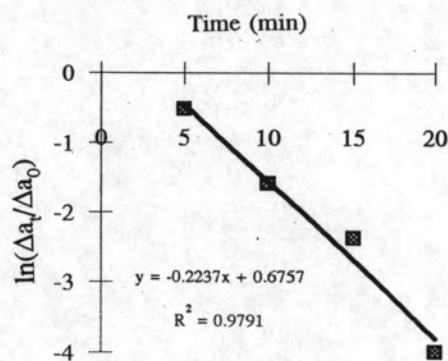
Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
S-T3/N1	0	0.5069	-	-
	5	0.8125	0.3055	-0.6225
	10	0.9375	0.125	-1.5164
	15	1.0069	0.0694	-2.1041
	20	1.0417	0.0347	-2.7974
	30	1.04861	0.0069	-4.4066
	35	1.0555	0.0069	-4.4066
	45	1.0625	0.0069	-4.4066
	50	1.0694	0.0069	-4.4066
	55	1.0764	0.0069	-4.4066
S-T3/N2	0	0.4514	-	-
	5	0.7292	0.2778	-0.4855
	10	0.8333	0.1042	-1.4663
	15	0.875	0.0417	-2.3827
	20	0.8889	0.0139	-3.4812
	25	0.8958	0.0069	-4.1743
	30	0.9028	0.0069	-4.1743
S-T3/N3	0	0.5417	-	-
	5	0.8472	0.3055	-0.7484
	10	0.9861	0.1389	-1.5369
	15	1.0555	0.0694	-2.2301
	20	1.0833	0.02778	-3.1461
	25	1.1097	0.0269	-3.1978
	30	1.1319	0.0222	-3.3693
	35	1.1458	0.0139	-3.8394
	40	1.1597	0.0139	-3.8397
	50	1.1667	0.0069	-4.5325
	60	1.1806	0.0139	-3.8394
	90	1.1875	0.0069	-4.5325

Variation of  $\ln(\Delta a_t/\Delta a_0)$  with swelling time.

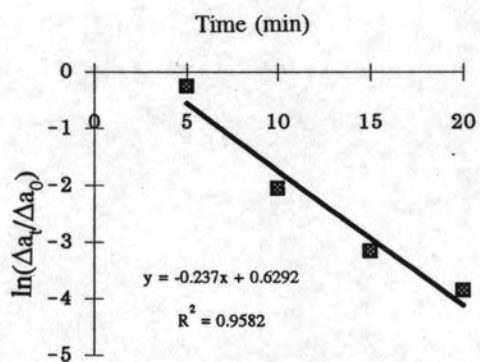
Seed and large beads were prepared by using toluene as diluent.



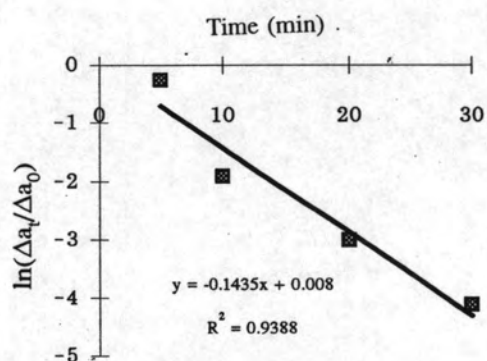
C-T0/N1



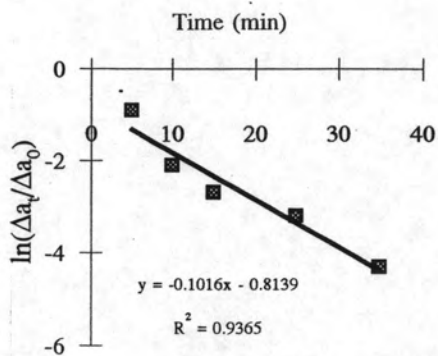
C-T0/N3



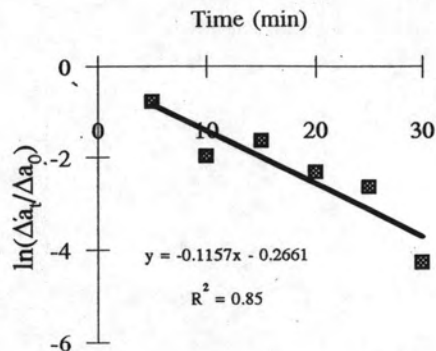
C-T3/N1



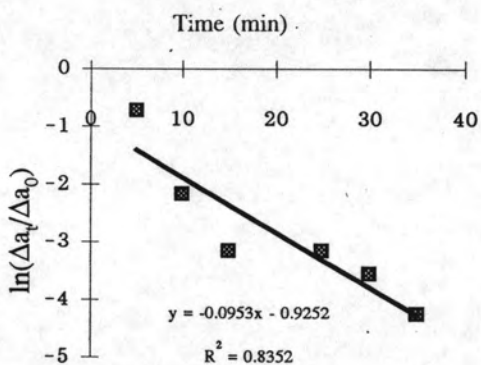
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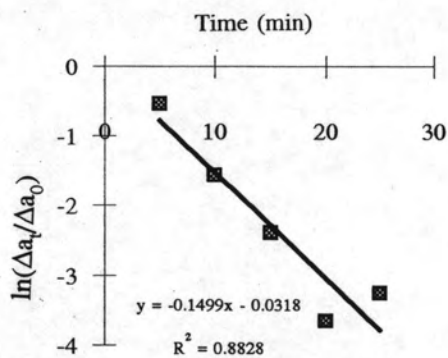
S-T0/N1



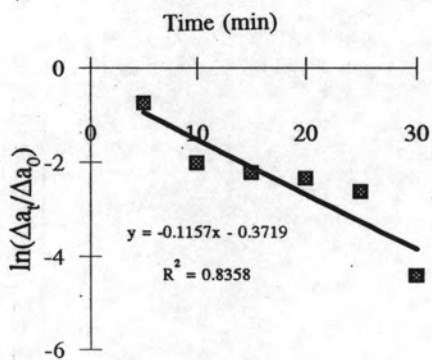
S-T0/N2



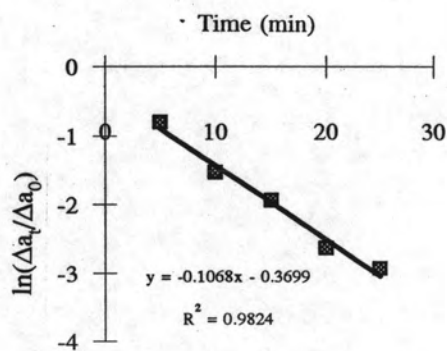
S-T0/N3



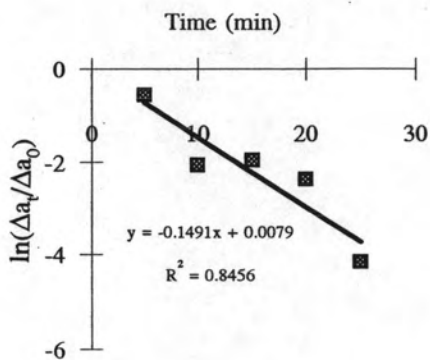
S-T1/N1



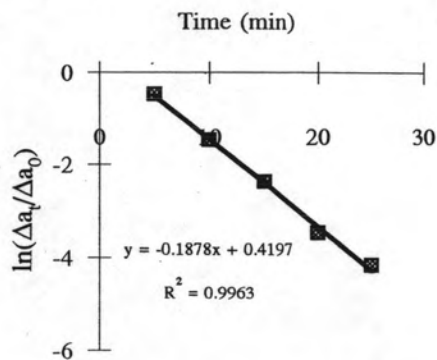
S-T1/N2



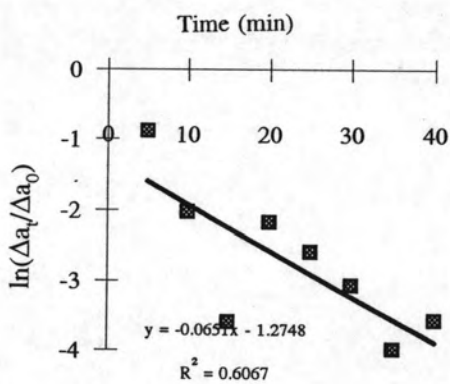
S-T1/N3



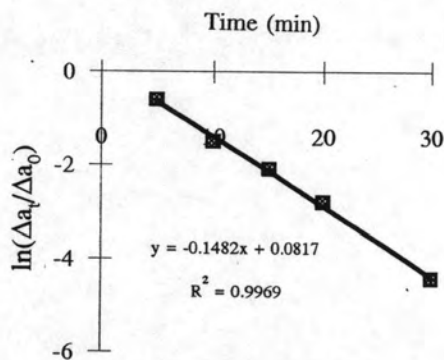
S-T2/N1



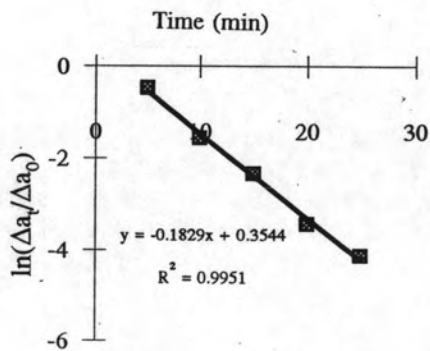
S-T2/N2



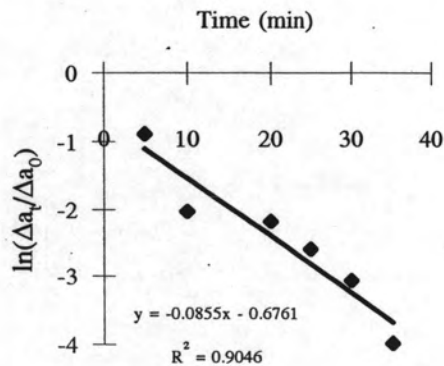
S-T2/N3



S-T3/N1



S-T3/N2



S-T3/N3



**Table C-2** Data for the calculation of the diffusion coefficient of the seed and large beads prepared by using n-heptane as diluent.

Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
C-H1/N1	0	0.3125	-	-
	5	0.6181	0.2014	-0.7598
	10	0.6875	0.0555	-2.0478
	15	0.7153	0.0139	-3.4332
	20	0.7292	0.0069	-4.1263
	25	0.7361	0.0055	-4.3513
	35	0.7431	0.0084	-3.9428
	45	0.7431	0.0069	-4.1263
C-H3/N1	0	0.4375	-	-
	5	0.6667	0.2292	-0.6144
	10	0.7292	0.0625	-1.9136
	15	0.75	0.0209	-3.0114
	20	0.7639	0.0139	-3.4169
	25	0.7778	0.0139	-3.4169
	35	0.8333	0.0555	-2.0315
	45	0.8487	0.0153	-3.3177
	50	0.8611	0.0124	-3.5311
S-H1/N1	0	0.4097	-	-
	5	0.6944	0.2847	-0.4136
	10	0.7778	0.0833	-1.6422
	15	0.7861	0.0083	-3.9452
	20	0.7986	0.0125	-3.5394
	25	0.8055	0.0069	-4.1271
	30	0.8194	0.0139	-3.4339
	45	0.8264	0.0069	-4.1271
	55	0.8333	0.0069	-4.1271
	60	0.8403	0.0069	-4.1271

(continued)

Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
S-H1/N2	0	0.5417	-	-
	5	0.8472	0.3055	-0.7484
	10	0.9861	0.1389	-1.5369
	15	1.0555	0.0694	-2.2301
	20	1.0833	0.0278	-3.1461
	25	1.1097	0.0264	-3.1977
	30	1.1319	0.0222	-3.3693
	35	1.1458	0.0139	-3.8394
	40	1.1597	0.0139	-3.8397
	50	1.1667	0.0069	-4.5325
	60	1.1805	0.0139	-3.8394
	90	1.1875	0.0069	-4.5325
S-H1/N3	0	0.5764	-	-
	5	0.8819	0.3055	-0.5853
	10	0.9792	0.0972	-1.7304
	15	1.0069	0.0278	-2.9833
	20	1.0347	0.0278	-2.9831
	25	1.0625	0.0278	-2.9832
	30	1.0694	0.0069	-4.3698
	35	1.0903	0.0208	-3.2707
	40	1.0972	0.0069	-4.3695
	45	1.1042	0.0069	-4.3694
	50	1.1111	0.0069	-4.3698
	55	1.1181	0.0069	-4.3691
S-H2/N1	0	0.5347	-	-
	5	0.8472	0.3125	-0.5505
	10	0.9236	0.0764	-1.959
	15	0.9931	0.0694	-2.0541
	20	1.0208	0.0278	-2.9703
	25	1.0278	0.0069	-4.3566
	30	1.0416	0.0139	-3.6638

(continued)

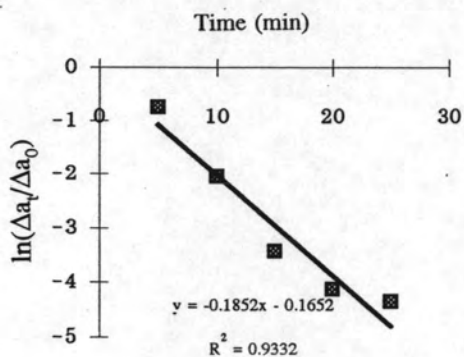
Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
	35	1.0555	0.0139	-3.6638
	40	1.0625	0.0069	-4.3566
	50	1.0764	0.0139	-3.6635
S-H2/N2	0	0.4861	-	-
	5	0.7639	0.2778	-0.4543
	10	0.8264	0.0625	-1.9459
	15	0.8819	0.0555	-2.0637
	20	0.8958	0.0139	-3.4499
	25	0.9028	0.0069	-4.1431
	30	0.9097	0.0069	-4.1438
	40	0.9167	0.0069	-4.1431
	45	0.9236	0.0069	-4.1431
S-H2/N3	0	0.5417	-	-
	5	0.7917	0.25	-0.5274
	10	0.875	0.0833	-1.626
	15	0.9236	0.0486	-2.165
	20	0.9444	0.0208	-3.0122
	25	0.9583	0.0139	-3.4177
	30	0.9653	0.0069	-4.1108
S-H3/N1	0	0.5625	-	-
	5	0.7569	0.1944	-0.5596
	10	0.8264	0.0694	-1.5892
	15	0.8681	0.0417	-2.1001
	20	0.8958	0.0278	-2.5054
	25	0.9028	0.0069	-3.8917

(continued)

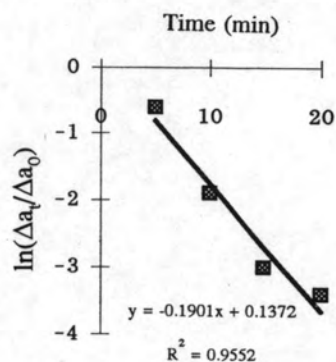
Sample code	Time (min)	Bead radius (a, mm)	$\Delta a_t$ (mm)	$\ln(\Delta a_t/\Delta a_0)$
S-H3/N2	0	0.4375	-	-
	5	0.7847	0.3472	-0.5188
	10	0.8809	0.0962	-1.8021
	15	0.9305	0.0496	-2.4646
	20	0.9722	0.0417	-2.6391
	25	1	0.0278	-3.0444
	35	1.0069	0.0069	-4.4307
	45	1.0139	0.0069	-4.4307
	50	1.0208	0.0069	-4.4307
S-H3/N3	0	0.4792	-	-
	5	0.6875	0.2083	-0.4489
	10	0.7361	0.0486	-1.9043
	15	0.7569	0.0208	-2.7517
	20	0.7778	0.0208	-2.7517
	25	0.7847	0.0069	-3.8494
	40	0.7986	0.0139	-3.1569
	90	0.8055	0.0069	-3.8508

Variation of  $\ln(\Delta a_t/\Delta a_0)$  with swelling time.

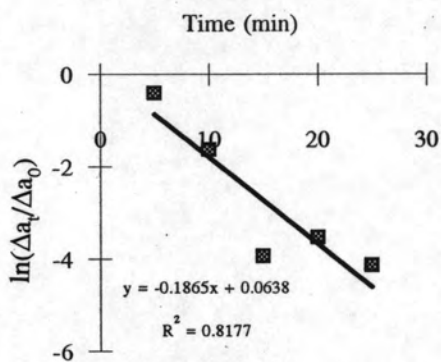
Seed and large beads were prepared by using n-heptane as diluent.



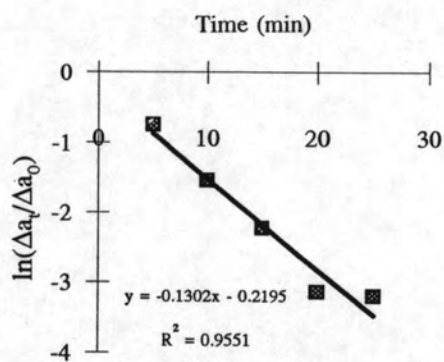
C-H1/N1



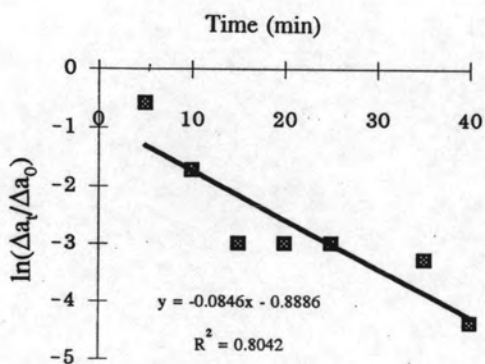
C-H3/N1



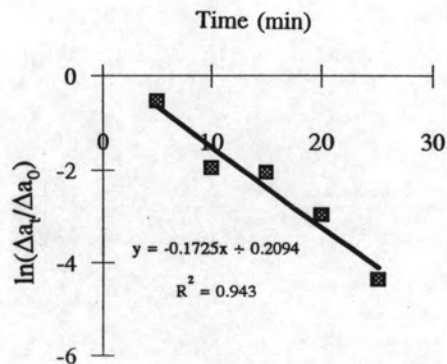
S-H1/N1



S-H1/N2

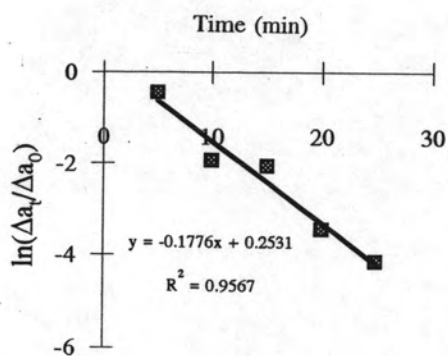


S-H1/N3

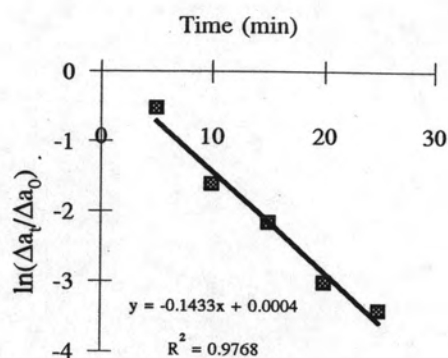


S-H2/N1

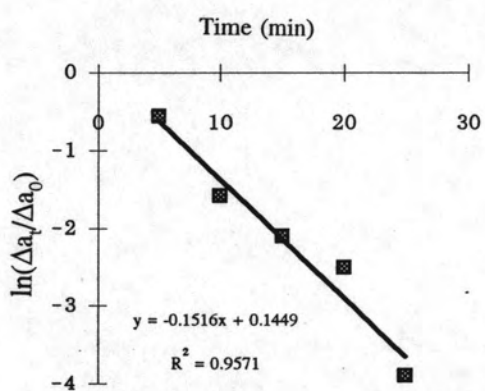




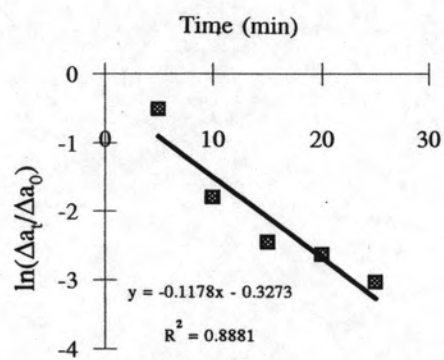
S-H2/N2



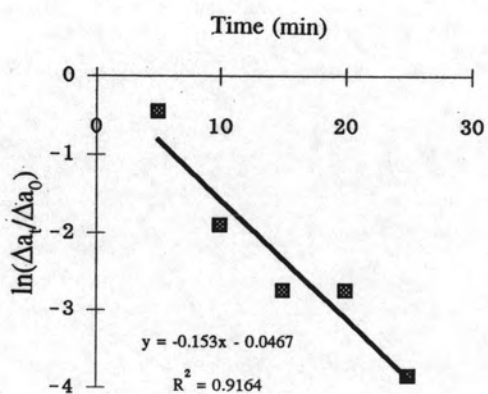
S-H2/N3



S-H3/N1



S-H3/N2



S-H3/N3

## APPENDIX D

### Data of Pore Properties

**Table D-1** Specific surface area vs adsorption and desorption rate

Sample code	Specific surface area (m <sup>2</sup> /g)	Adsorption rate (mm <sup>3</sup> /min)	Desorption rate (mm <sup>3</sup> /min)
C-H3/N2	0.6832	0.1074	0.1354
C-H3/N3	0.9627	0.0882	0.1830
C-H2/N1	1.1116	0.0937	0.1078
C-H2/N3	1.2018	0.1023	0.1723
C-H1/N3	138.9610	0.1112	0.1619
C-H2/N2	139.8736	0.1417	0.1880
S-H1/N2	0.7831	0.3765	0.5827
S-H2/N2	0.8473	0.2773	0.4042
S-H3/N3	0.9985	0.1801	0.2596
S-H3/N2	1.8930	0.3348	0.3693
S-H1/N3	2.3629	0.4144	0.4716
S-H2/N3	137.7620	0.2826	0.4100
C-T3/N2	0.0734	0.0493	0.0559
C-T3/N1	0.3887	0.1052	0.1592
C-T2/N1	0.4912	0.0538	0.0644
C-T1/N3	0.9573	0.1033	0.1765
C-T3/N3	2.7095	0.1557	0.2393
C-T2/N1	155.0299	0.1485	0.2373
S-T2/N1	0.5944	0.6127	0.7547
S-T1/N3	2.1586	0.1851	0.2722
S-T3/N3	2.7394	0.6515	0.7694
S-T2/N3	156.3724	0.3064	0.3763

**Table D-2** Average pore diameter vs adsorption and desorption rate

Sample code	Average pore diameter (Å)	Adsorption rate (mm <sup>3</sup> /min)	Desorption rate (mm <sup>3</sup> /min)
C-H3/N3	10.0299	0.0882	0.1830
C-H3/N2	11.5427	0.1074	0.1354
C-H2/N2	33.5914	0.1417	0.1880
C-H1/N3	33.5914	0.1112	0.1619
C-H2/N1	35.0037	0.0937	0.1078
C-H2/N3	58.8257	0.1023	0.1723
S-H2/N2	0.5752	0.2773	0.4042
S-H3/N3	13.7355	0.1801	0.2596
S-H3/N2	28.9954	0.3348	0.3693
S-H1/N3	30.7263	0.4144	0.4716
S-H2/N3	33.4918	0.2826	0.4100
S-H1/N2	98.0767	0.3765	0.5827
C-T3/N3	30.3641	0.1557	0.2393
C-T2/N1	33.7568	0.1485	0.2373
C-T1/N3	37.7283	0.1033	0.1765
C-T2/N1	95.7952	0.0538	0.0644
C-T3/N1	113.6994	0.1052	0.1592
C-T2/N2	222.6100	0.0493	0.0559
S-T1/N3	15.6947	0.1851	0.2722
S-T3/N3	22.3438	0.6515	0.7694
S-T2/N3	33.2920	0.3064	0.3763
S-T2/N1	128.2050	0.6127	0.7547

## VITA

Miss Sumon Traisaranapong was born on July 24, 1968 in Bangkok, Thailand. She received her B. Sc. degree in Industrial Chemistry from the Faculty of Science, King Mongkut's Institute of Technology Ladkrabang in 1992 and she has been a graduate student in the Multidisciplinary Program of Petrochemistry-Polymer, Polymer Science Division, Graduate School, Chulalongkorn University since 1992.