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SELECTIVITY OF AN OCTADECYL-MODIFIED VINYL ALCOHOL COPOLYMER GEL FOR THE RETENTION OF POLAR COMPOUNDS

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SUMMARY

The enthalpies of phenols and aromatic acids were measured in order to characterize their behaviour on an octadecyl-bonded vinyl alcohol copolymer gel in reversed-phase liquid chromatography. These values were compared with the enthalpies measured on an octadecyl-bonded silica gel. The enthalpies of non-polar compounds, measured on an octadecyl-bonded silica gel, were higher than those obtained on the bonded vinyl alcohol copolymer gel. However, the enthalpies of phenols and aromatic acids were higher than those obtained on an octadecyl-bonded silica gel. This means that hydrogen bonding may be involved in the retention of phenols and aromatic acids on this vinyl alcohol copolymer gel.

INTRODUCTION

The retention of hydrophobic compounds on an octadecyl-bonded vinyl alcohol copolymer gel was investigated in relation to their Van der Waals volumes and a selectivity index representing the energy effect related to delocalization energy as used previously in reversed-phase liquid chromatography^{1,2}. The selectivity index, R^* related to various intermolecular interactions is given by the equation

$$R = R_v + R^*$$

where R is the retention time of the analyte and R_v is the molecular size index, defined as the retention of a hypothetical n -alkane having the same Van der Waals volume as analyte. The retention time of highly hydrophobic compounds was longer than their predicted retention times on both an octadecyl-bonded silica gel³ and an octadecyl-bonded vinyl alcohol copolymer gel⁴. The difference between the experimental and predicted capacity ratio could be related to their enthalpies^{3,4}. The value of the enthalpy effect of alkylbenzenes in which the alkyl chain was longer than six carbon atoms increased dramatically with increasing chain length, but the value of the selectivity index became fairly constant^{3,4}. Direct adsorption of solutes on the surface of these packings could therefore be the predominant force in the retention of the larger sized alkylbenzenes on an octadecyl-bonded vinyl alcohol copolymer gel and on an octadecyl-bonded silica gel. Further, the enthalpy effect of polyaromatic hydro-

TABLE I
 PHYSICAL PARAMETERS AND THE LOGARITHM OF CAPACITY RATIOS (k') OF PHENOLS

Experimental conditions: column, BHST 602 C₁₈ (10 cm × 6 mm I.D.); eluent, 50% aqueous acetonitrile containing 0.05 M phosphoric acid; flow-rate, 1 ml/min.

No.	Compound	VWV ^a	Log k'	Temperature [$1/T$ ($K^{-1} \cdot 10^5$)]											S^b	$-\Delta H$	$-\Delta HF$
				309.6	314.5	319.5	324.7	330.0	335.6	341.3	347.2						
1	Phenol	53.88	-0.322	-0.298	-0.271	-0.242	-0.219	-0.193	-0.162	-0.126	9.218	2.344	1.980				
2	2-Methylphenol	65.03	-0.166	-0.139	-0.104	-0.089	-0.064	-0.050	-0.018	0.015	8.127	2.088	1.683				
3	4-Methylphenol	65.03	-0.241	-0.210	-0.180	-0.164	-0.139	-0.116	-0.084	-0.050	9.816	2.217	1.910				
4	2,3-Dimethylphenol	76.18	-0.052	-0.029	0.004	0.027	0.050	0.063	0.090	0.125	8.330	2.062	1.926				
5	2,4-Dimethylphenol	76.18	-0.080	-0.050	-0.018	-0.005	0.016	0.036	0.062	0.085	8.662	1.922	1.872				
6	2,5-Dimethylphenol	76.18	-0.085	-0.054	-0.027	-0.012	0.007	0.028	0.057	0.094	8.683	2.023	1.880				
7	2,6-Dimethylphenol	76.18	-0.050	-0.024	0.002	0.020	0.038	0.055	0.080	0.109	8.456	1.836	1.941				
8	3,4-Dimethylphenol	76.18	-0.158	-0.130	-0.103	-0.083	-0.061	-0.042	-0.010	0.018	9.925	2.067	1.906				
9	3,5-Dimethylphenol	76.18	-0.149	-0.119	-0.090	-0.074	-0.054	-0.034	-0.007	0.023	9.833	1.979	1.889				
10	2,3,5-Trimethylphenol	87.33	0.031	0.055	0.088	0.110	0.132	0.144	0.168	0.211	9.247	2.043	1.947				
11	2,3,6-Trimethylphenol	87.33	0.054	0.082	0.112	0.127	0.146	0.159	0.185	0.208	9.027	1.775	1.940				
12	2,4,6-Trimethylphenol	87.33	0.052	0.073	0.105	0.122	0.139	0.148	0.171	0.192	9.101	1.635	1.898				
13	2,3,5,6-Tetramethylphenol	98.48	0.164	0.188	0.217	0.234	0.251	0.261	0.282	0.309	-	1.654	1.960				
14	2-Ethylphenol	75.26	-0.050	-0.021	0.011	0.030	0.053	0.070	0.097	0.115	8.272	1.968	1.877				
15	3-Ethylphenol	75.26	-0.138	-0.107	-0.071	-0.043	-0.016	0.010	0.046	0.086	9.246	2.641	1.838				
16	4-Ethylphenol	75.26	-0.142	-0.113	-0.082	-0.063	-0.045	-0.027	0.003	0.032	9.314	2.008	1.886				

17	2-Chlorophenol	63.03	-0.078	-0.048	-0.015	0.006	0.034	0.059	0.081	0.138	6.661	2.445	1.899
18	3-Chlorophenol	63.03	0.018	0.054	0.093	0.119	0.153	0.173	0.210	0.264	5.261	2.817	2.118
19	4-Chlorophenol	63.03	-0.015	0.021	0.053	0.085	0.113	0.145	0.177	0.222	5.700	2.783	2.085
20	2,3-Dichlorophenol	72.51	0.182	0.219	0.257	0.285	0.315	0.340	0.377	0.417	4.362	2.752	2.061
21	2,4-Dichlorophenol	72.51	0.253	0.286	0.327	0.356	0.385	0.411	0.450	0.488	3.555	2.784	2.029
22	2,5-Dichlorophenol	72.51	0.249	0.289	0.325	0.353	0.383	0.404	0.442	0.447	3.511	2.663	2.031
23	2,6-Dichlorophenol	72.51	0.143	0.171	0.201	0.224	0.246	0.266	0.298	0.326	5.207	2.163	2.032
24	3,4-Dichlorophenol	72.51	0.266	0.308	0.349	0.381	0.413	0.442	0.482	0.521	3.149	3.006	2.133
25	3,5-Dichlorophenol	72.51	0.403	0.446	0.489	0.523	0.555	0.581	0.619	0.656	2.091	2.981	2.209
26	2,3,4-Trichlorophenol	81.99	0.459	0.496	0.542	0.579	0.615	0.629	0.663	0.704	3.063	2.880	2.083
27	2,3,5-Trichlorophenol	81.99	0.568	0.611	0.655	0.703	0.730	0.762	0.810	0.852	1.897	3.376	2.374
28	2,3,6-Trichlorophenol	81.99	0.382	0.412	0.447	0.478	0.503	0.524	0.560	0.587	3.442	2.463	2.093
29	2,4,5-Trichlorophenol	81.99	0.531	0.571	0.623	0.667	0.696	0.731	0.771	0.814	2.199	3.376	2.157
30	3,4,5-Trichlorophenol	81.99	0.590	0.634	0.678	0.728	0.752	0.784	0.826	0.872	1.651	3.319	2.335
31	2,3,4,5-Tetrachlorophenol	91.47	0.776	0.824	0.871	0.923	0.951	0.980	1.024	1.067	1.438	3.434	2.470
32	2,3,5,6-Tetrachlorophenol	91.47	0.675	0.709	0.754	0.791	0.810	0.831	0.866	0.904	2.880	2.670	2.251
33	Pentachlorophenol	100.95	0.885	0.926	0.972	1.012	1.029	1.051	1.088	1.127	2.497	2.791	2.439
34	3-Bromophenol	66.48	0.087	0.125	0.163	0.189	0.224	0.250	0.286	0.317	4.374	2.747	2.039
35	4-Bromophenol	66.48	0.060	0.099	0.138	0.165	0.197	0.228	0.262	0.301	4.578	2.842	2.024
36	2,4-Dibromophenol	79.08	0.400	0.443	0.484	0.520	0.550	0.577	0.612	0.654	3.041	2.974	2.021

^a Van der Waals volume (cm³/mol) calculated by Bondi's method.

^b Selectivity index (units), obtained on BHST 602 C₁₈.

^c Enthalpy effect (kcal/mol), obtained on ERC-1000 (ODS-silica gel) from ref. 7 (eluent, 70% aqueous acetonitrile containing 0.05 M phosphoric acid).

TABLE II
 PHYSICAL PARAMETERS AND THE LOGARITHM OF CAPACITY RATIOS (k') OF AROMATIC ACIDS

Experimental conditions: column, BHST 602 C₁₈ (10 cm × 6 mm I.D.); eluent, 30% aqueous acetonitrile containing 0.05 M phosphoric acid; flow-rate, 1 ml/min.

No.	Compound	VW ¹⁰	Log k'	Temperature [$1/T$ ($K^{-1} \cdot 10^5$)]											S^b	$-\Delta H$	$-\Delta H^c$
				309.6	314.4	319.5	324.7	330.0	335.6	341.3	347.2	353.0	358.7	364.4			
1	Benzoic acid	65.36	0.063	0.102	0.146	0.186	0.232	0.278	0.332	0.370	9.131	3.796	2.400				
2	2-Methylbenzoic acid	76.51	0.246	0.290	0.334	0.376	0.419	0.475	0.510	0.564	9.278	3.847	2.647				
3	3-Methylbenzoic acid	76.51	0.269	0.307	0.358	0.399	0.443	0.495	0.535	0.586	9.264	3.869	2.555				
4	4-Methylbenzoic acid	76.51	0.252	0.290	0.343	0.382	0.436	0.492	0.523	0.578	9.278	4.004	2.540				
5	2,4-Dimethylbenzoic acid	87.66	0.460	0.502	0.553	0.604	0.648	0.697	0.742	0.796	9.423	4.085	2.769				
6	2,5-Dimethylbenzoic acid	87.66	0.446	0.489	0.544	0.586	0.638	0.680	0.727	0.776	9.440	4.014	2.830				
7	2,6-Dimethylbenzoic acid	87.66	0.106	0.145	0.186	0.218	0.254	0.298	0.328	0.372	9.791	3.193	2.311				
8	3,4-Dimethylbenzoic acid	87.66	0.425	0.467	0.521	0.567	0.621	0.661	0.708	0.763	9.457	4.101	2.696				
9	3,5-Dimethylbenzoic acid	87.66	0.480	0.520	0.574	0.615	0.660	0.714	0.752	0.801	9.416	3.926	2.754				
10	2,4,6-Trimethylbenzoic acid	98.81	0.324	0.353	0.410	0.446	0.495	0.530	0.565	0.608	9.919	3.502	2.518				
11	4-Ethylbenzoic acid	86.74	0.468	0.507	0.560	0.605	0.661	0.707	0.749	0.800	9.396	4.087	2.771				
12	2-Chlorobenzoic acid	74.84	0.186	0.230	0.274	0.316	0.368	0.415	0.455	0.504	9.294	3.880	2.652				
13	3-Chlorobenzoic acid	74.84	0.505	0.550	0.604	0.655	0.707	0.763	0.801	0.867	8.963	4.379	2.915				
14	4-Chlorobenzoic acid	74.84	0.509	0.554	0.613	0.663	0.722	0.773	0.827	0.881	8.961	4.571	2.934				
15	2,4-Dichlorobenzoic acid	84.32	0.665	0.712	0.768	0.824	0.872	0.926	0.976	1.036	9.094	4.502	3.051				
16	2,5-Dichlorobenzoic acid	84.32	0.616	0.665	0.727	0.771	0.834	0.878	0.931	0.992	9.161	4.541	3.068				

17	2,6-Dichlorobenzoic acid	84.32	0.298	0.333	0.381	0.409	0.448	0.492	0.533	0.577	9.499	3.374	2.539
18	3,4-Dichlorobenzoic acid	84.32	0.880	0.936	1.003	1.055	1.123	1.178	1.240	1.299	9.059	5.116	3.332
19	3,5-Dichlorobenzoic acid	84.32	0.976	1.030	1.092	1.158	1.208	1.263	1.312	1.368	8.765	4.778	3.283
20	2-Bromobenzoic acid	77.96	0.266	0.307	0.361	0.403	0.457	0.503	0.552	0.602	9.307	4.115	2.805
21	3-Bromobenzoic acid	77.96	0.596	0.641	0.706	0.772	0.821	0.867	0.917	0.972	8.961	4.620	3.075
22	4-Bromobenzoic acid	77.96	0.607	0.656	0.720	0.772	0.832	0.887	0.917	1.007	8.946	4.732	3.105
23	Phenylacetic acid	79.55	-0.136	-0.098	-0.063	-0.028	0.015	0.059	0.086	0.134	9.777	3.265	2.462
24	2-Tolylacetic acid	86.74	0.116	0.157	0.200	0.237	0.287	0.330	0.363	0.408	9.858	3.562	2.758
25	3-Tolylacetic acid	86.74	0.258	0.297	0.347	0.390	0.446	0.491	0.530	0.575	9.909	3.924	2.994
26	2-Chlorophenylacetic acid	85.07	0.172	0.049	0.094	0.125	0.172	0.209	0.240	0.283	9.705	2.187	2.544
27	4-Chlorophenylacetic acid	85.07	0.062	0.096	0.140	0.176	0.222	0.260	0.293	0.338	9.558	3.369	2.592
28	4-Phenyl- <i>n</i> -butyric acid	96.05	0.229	0.274	0.310	0.351	0.391	0.444	0.475	0.522	9.941	3.548	2.835
29	1(+)-Mandelic acid	80.18	0.588	-0.545	-0.519	-0.507	-0.475	-0.436	-0.422	-0.398	10.23	2.254	1.562
30	<i>trans</i> -Cinnamic acid	82.32	0.251	0.299	0.352	0.396	0.448	0.510	0.551	0.612	9.471	4.376	2.884
31	4-Methylcinnamic acid	93.47	0.467	0.512	0.571	0.621	0.687	0.738	0.788	0.856	9.592	4.738	3.039
32	3-Phenyl- <i>n</i> -propionic acid	86.04	0.060	0.102	0.145	0.182	0.220	0.275	0.306	0.355	9.789	3.563	2.767
33	Indole-3-acetic acid	91.65	-0.013	0.036	0.098	0.145	0.206	0.266	0.316	0.376	9.979	4.755	3.170
34	Indole-3-propionic acid	114.11	0.178	0.235	0.298	0.351	0.412	0.489	0.532	0.604	10.56	5.174	3.528
35	Indole-3-butyric acid	121.34	0.307	0.364	0.426	0.482	0.558	0.621	0.671	0.744	10.61	5.330	3.711
36	Hippuric acid	96.15	-0.729	-0.689	-0.671	-0.655	-0.633	-0.581	-0.586	-0.559	10.86	2.022	1.406

^{a,b} See Table I.

^c Enthalpy effect (kcal/mol), obtained on ERC-1000 (ODS-silica gel), from ref 12 (eluent, 30% aqueous acetonitrile containing 0.05 M phosphoric acid).

carbons was larger than that of alkylbenzenes on this vinyl alcohol copolymer gel compared with their retention on an octadecyl-bonded silica gel, which means that polyaromatic hydrocarbons are selectively retained on this organic packing⁴.

The effect of temperature on the retention of phenols and aromatic acids was therefore measured, and their enthalpies were obtained in order to study the retention mechanism of polar compounds on this modified vinyl alcohol copolymer gel.

EXPERIMENTAL

The details of the chromatograph were described previously⁴. The 9- μm vinyl alcohol copolymer gel was BHST 602 C₁₈ from Asahi Chemical (Kawasaki, Japan). The 10 cm \times 6.0 mm I.D. packed column was thermostated at 15–50°C in a circulating water-bath (Ikedarika, Tokyo, Japan). The chemicals and their physical parameters are given in Table I.

RESULTS AND DISCUSSION

The capacity ratios of phenols, measured on an octadecyl-bonded vinyl alcohol copolymer gel at different temperatures, are given in Table I, together with their Van der Waals volumes, and the values for aromatic acids are given in Table II. The selectivity index was obtained from refs. 5 and 6. The enthalpy effect, measured on an octadecyl-bonded silica gel, was obtained from ref. 7. The correlation coefficient of the log k' values of phenols between this octadecyl-bonded vinyl alcohol copolymer gel and silica gel² was 0.889 ($n = 34$). The chromatographic behaviour of phenols on this organic polymer gel appeared to be similar to that on an octadecyl-bonded silica gel.

The correlation coefficient of the log k' values of aromatic acids between the octadecyl-bonded vinyl alcohol copolymer gel and the octadecyl-bonded silica gel⁸ was 0.908 ($n = 35$), a value similar to that obtained for phenols.

The partition coefficient between octanol and water (log P) is a useful parameter for the optimization of reversed-phase liquid chromatography on polystyrene gel⁹, and the correlation coefficient between the log P and log k' values, measured at 30°C, of phenols and aromatic acids was therefore calculated. The value was 0.915 ($n = 36$) and 0.858 ($n = 36$) for phenols and aromatic acids, respectively. These values are poor compared with those obtained on octadecyl-bonded silica gels^{10,11}, which indicates the existence of selectivity of this octadecyl-bonded vinyl alcohol copolymer gel in contrast to octadecyl-bonded silica gels. A further study was carried out of the difference in the enthalpy effects of phenols and aromatic acids.

The relationship between log k' for phenols and the reciprocal of the absolute temperature was linear. Although this linear relationship changed slightly at about 33°C, as found in the retention of alkyl compounds⁴, no negative enthalpy effect was observed in the retention of phenols. The calculated values of the enthalpy effect for phenols are given in Table I. The enthalpy effect of alkylphenols was about 2.0 kcal/mol and the energy effect was about 9.0 units⁵. The enthalpy effect of halogenated phenols was about 2.9 kcal/mol. However, the energy effect decreased from 9.2 units for phenol to 2.5 units for pentachlorophenol. Permethyphenols have lower enthalpy and perchlorophenols higher enthalpy than phenol, as shown in Figs. 1 and 2.

The enthalpy effect of alkylphenols was almost constant on octadecyl-bonded

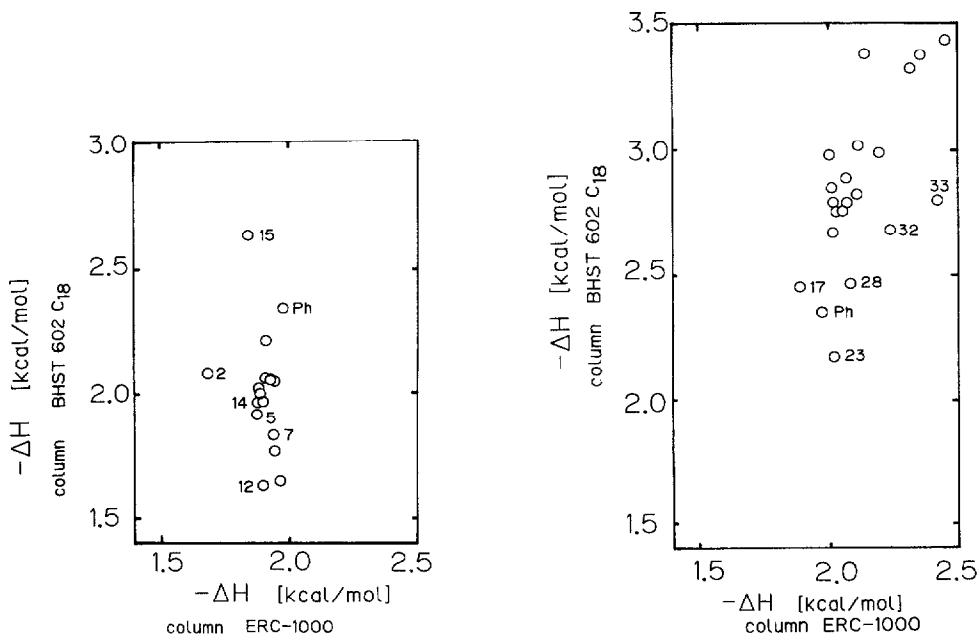


Fig. 1. Comparison of octadecyl-bonded vinyl alcohol copolymer and silica gels as a function of enthalpy for the retention of alkylphenols. For experimental conditions see Table I. Numbers next to symbols correspond to those in Table I. Ph = Phenol.

Fig. 2. Comparison of octadecyl-bonded vinyl alcohol copolymer and silica gels as a function of enthalpy for the retention of halogenated phenols. For experimental conditions, see Table I. Numbers next to symbols correspond to those in Table I.

silica gel, but on the organic polymer gel it varied from about 1.6 to 2.6 kcal/mol, as shown in Fig. 1. There was, therefore, no good correlation between the enthalpy of alkylphenols measured on the organic polymer gel and that measured on the silica gel ($r = 0.226$, $n = 16$). The enthalpy of halogenated phenols varied from about 1.9 to 2.5 kcal/mol on the octadecyl-bonded silica gel but from about 2.2 to 3.4 kcal/mol on the organic polymer gel. The correlation coefficient between the enthalpy measured on the organic polymer gel and that measured on the silica gel for halogenated phenols was 0.656 ($n = 21$). However, it was improved to 0.872 ($n = 17$) by excluding the *ortho*-substituted halogenated phenols. The correlation coefficient for phenols was 0.765 ($n = 36$). This poor correlation and the variation of the enthalpies of polar compounds indicate the existence of steric selectivity of this organic polymer gel. Their capacity ratios measured on the organic polymer gel were smaller than those measured on the octadecyl-bonded silica gel, whereas the enthalpy effect measured on the octadecyl-bonded vinyl alcohol copolymer gel was greater than that on the octadecyl-bonded silica gel. However, the enthalpies of hydrophobic compounds measured on the octadecyl-bonded silica gel were higher than those obtained on the organic polymer gel. This result indicates that phenols could further be adsorbed by hydrogen bonding on the organic polymer gel, even though the enthalpy effect was weaker than the selectivity index, and such adsorption was not the predominant retention force.

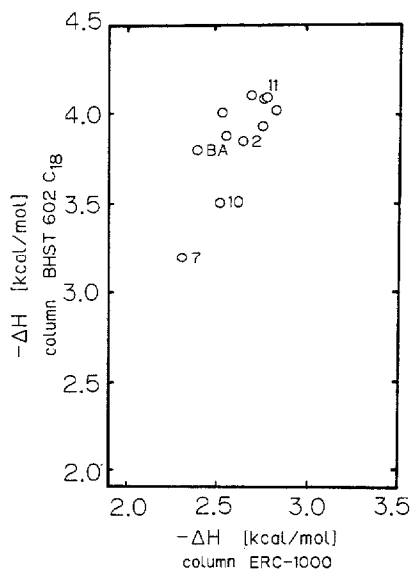


Fig 3. Comparison of octadecyl-bonded vinyl alcohol copolymer and silica gels as a function of enthalpy for the retention of alkylbenzoic acids. For experimental conditions, see Table II. Numbers next to symbols correspond to those in Table II. BA = Benzoic acid.

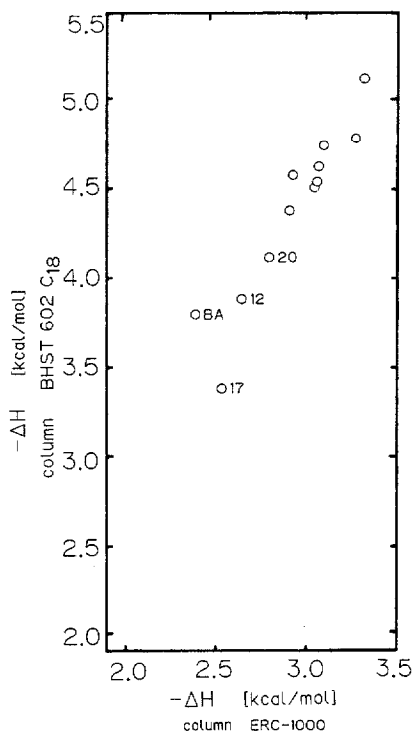


Fig. 4. Comparison of octadecyl-bonded vinyl alcohol copolymer and silica gels as a function of enthalpy for the retention of halogenated benzoic acids. For experimental conditions, see Table II. Numbers next to symbols correspond to those in Table II.

A similar result was obtained for the chromatographic behaviour of aromatic acids, their capacity ratios being small and their enthalpy effect large on the organic polymer gel. The enthalpy effect varied from about 3.2 to 5.1 kcal/mol on the octadecyl-bonded vinyl alcohol copolymer gel and from about 2.3 to 3.3 kcal/mol on the octadecyl-bonded silica gel¹², as shown in Figs. 3 and 4.

The correlation coefficient between the enthalpy of aromatic acids ($n = 36$) measured on the organic polymer gel and that on the silica gel was 0.899; the value was 0.942 ($n = 22$) only for benzoic acids. The enthalpy effect of aromatic acids was stronger than that of phenols on the octadecyl-bonded vinyl alcohol copolymer gel. Further, *ortho*-disubstituted aromatic acids were less retained on the organic polymer gel, as with substituted phenols. These results indicate that the carboxyl group of benzoic acids is involved in their retention on the octadecyl-bonded vinyl alcohol copolymer gel, even though their enthalpy effect was weaker than their selectivity index.

This selective retention of polar compounds on the organic polymer gel, compared with their chromatographic behaviour on octadecyl-bonded silica gel, may

be the reason why the vinyl alcohol copolymer gel was a powerful packing for the direct analysis of target compounds in urine and serum¹³.

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